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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1953 WASHINGTON MEETING

AT

WASHINGTON, D. C.

April 30, May 1 and 2, 1953

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AMERICAN PHYSICAL SOCIETY

1953 WASHINGTON MEETING, APRIL 30, MAY 1-2, 1953

IT is frightening to report that once again the size of the Washington meeting, as measured by the number of contributed papers—three hundred and eighty-seven—is going to set a new record, surpassing all previous meetings in Washington and elsewhere by a margin of nearly twenty percent. The dates of this gargantuan affair will be **Thursday, April 30, and Friday and Saturday, May 1 and 2, 1953.** The scenes of the sessions will again be the Shoreham Hotel, the Wardman Park Hotel, and the National Bureau of Standards. Thus we "get by" with the same accommodations as last year—but the sessions will average longer. The Local Committee, on which falls the heaviest of all such burdens hitherto encountered, consists of Hugh Odishaw (*Chairman*), R. G. Breckenridge, R. C. Herman, J. R. Pellam, and J. A. Sanderson. Owing to the magnitude of this Bulletin, the date of its delivery will probably be deplorably late. The members of the Society should consider whether they would rather have the deadline earlier: most protests, to date, have been in the opposite sense.

The **registration desk** will be located in the Shoreham Hotel. All members and guests are asked to register, and frequently to consult the nearby bulletin board for notice of messages.

A **registration fee** of one dollar will be requested. **Advance registrations** will mitigate the labors of the Local Committee: send yours (together with the dollar, and the payment for the dinner, if you will) to Mr. Hugh Odishaw, National Bureau of Standards, Washington 25, D. C.

Invited papers on the general programme will be given by J. R. Pellam and R. T. Webber in the field of cryogenics; by R. B. Breckenridge, C. L. Hogan, L. R. Maxwell, and F. L. Vogel in solid-state physics; by L. I. Schiff in theoretical physics; by L. Leprince-Ringuet and Manuel Sandoval Vallarta in cosmic-ray physics; by S. W. Barnes, F. J. Dyson, W. F. Fry, J. B. Platt, Emilio Segrè, Albert Silverman, and J. H. Tinlot on mesons; by L. T. Aldrich, W. H. Barkas, W. A. Fowler, H. W. Koch, W. F. Libby, M. M. Shapiro, and William Woodward in other departments of nuclear physics; by T. H. Johnson on the research programme of the Atomic Energy Commission; by J. A. Sanderson and C. A. Douglas on physics of the atmosphere; by H. H. Kurzweg on high speed flight; by C. K. Jen on microwave spectroscopy, and by A. G. Carlton on the design of filters.

Our **Division of Fluid Dynamics** has arranged a joint Symposium with the American Meteorological Society with papers by S. Chandrasekhar, Dave Fultz, and Jule Charney.

On the general programme figures a **Symposium on the reactions of transmutation in which hydrogen 3 and helium 3** are involved: the speakers are to be Arthur Hemmendinger, J. H. Fremlin, D. N. Kundu, S. Chandrasekhar, and S. T. Butler. It was intended to put this and the other Symposium on Saturday morning, but by a singular and possibly unique coincidence, the two have a speaker in common, and the Symposium on transmutation is displaced to Saturday afternoon.

Members of our **Division of Chemical Physics** are adjured that a Business Session of their Division will be held on Friday morning as part of Session L.

The **three hundred and eighty-seven contributed papers** are distributed among thirty sessions. Some remarks on the problems of sorting will be obtruded here.

The most embarrassing situations involve papers which are alone in their respective fields, so that no appropriate context can be found for them. These account for the greater part of Session X and for occasional papers scattered elsewhere. If there are two or three papers in a single field, the situation is less embarrassing but still appreciably so. (There are also authors who manage to write their abstracts in such a way that the Secretary

cannot figure out what they are about!) Some authors demand that their papers be listed with specified other papers in groups of two, three, and up to eight. Thus, of the papers UA10 through 14, one should have been in XA, one in N, one in KA, and two in S. It is natural for an author to suppose that he can locate his paper better than anyone else: the fallacy is that the author does not have the rest of the programme before him while the Secretary does. An art gallery will refuse a collection offered with the stipulation that all of the pictures must be hung together. Such a rule may be applied to our abstracts without further notice. Sometimes one or two papers are shifted into a less appropriate session to prevent the more appropriate session from shooting past 16 papers in length; this accounts for the placing of XA1 and XA2.

As usual, there are sessions labeled "reactions of transmutation and inelastic scattering" and sessions labeled "neutron physics." Information about nuclear energy levels is found in all. Some thought has been given to the idea of bringing all papers on nuclear energy levels into sessions so labeled, but the traditional scheme still seems the more desirable. The distribution of papers on machine-made mesons and stars with respect to papers on cosmic-ray mesons and stars still is a nightmare. There are not many papers in solid-state physics or in electron physics. The cultivators of these fields, like those of high-polymer physics, tend to prefer other meetings of the year; we dare not dissuade them, though the Washington meeting has acquired too strong a nuclear coloration. Not so easy to understand is the almost total vanishment of certain other fields which but lately produced two or more sessions apiece: for instance, nuclear magnetic resonance (has it gone over into chemistry?) and microwave spectroscopy (was it exhausted by the North Carolina meeting?).

Gratitude is expressed to W. W. Havens, Jr., and to R. L. Serber for assisting in the sorting of abstracts.

To get back to announcements:

The **banquet of the American Physical Society** will be held on Friday evening in the Terrace Room of the Shoreham. Contrary to what happened at Cambridge, evening dress will NOT be deprecated. The after-dinner speakers will be A. V. Astin and L. V. Berkner. The price of the dinner will be four dollars. Use the form on the inside back cover page of this Bulletin for advance reservation (this will be helpful to the hotel); and be reminded that you may include your check for the dinner with the registration fee if dispatched in advance to the Chairman of the Local Committee.

Tea will be served to members of the Society and their families at the Manse (on the grounds of the National Bureau of Standards) on Thursday afternoon between 4:30 and 6:30.

The **Nominating Committee of the American Physical Society** will meet on Friday at 4:15 P.M. in the Conference Room of the South Building of the National Bureau of Standards. This Committee consists of J. H. Van Vleck (*Chairman*), W. H. Brattain, D. M. Dennison, S. A. Goudsmit, F. W. Loomis, L. Marton, L. I. Schiff, A. M. Weinberg, and J. A. Wheeler.

The **Council of the American Physical Society** will meet on **Wednesday** at 2:00 P.M. in the Conference Room of the South Building of the National Bureau of Standards, unless a contrary notice is distributed to its members.

The American Institute of Physics will operate a **Placement Service Register** at the Shoreham. Employers and applicants should report to the Register upon arrival at the meeting.

The American Institute of Physics will conduct a scientific **Book Exhibit** at which the leading technical publishers will show their latest texts. The exhibit will be located in The Shoreham.

The **Sigma Pi Sigma luncheon** will be held on Friday at 12:30 in the Tilden Gardens Hotel dining room on Connecticut Avenue just south of the Bureau. Tickets at $1.75 will be on sale at the registration desk until 10:00 on Friday morning, and should be reserved in advance by letter to Dr. Marsh W. White, Osmond Laboratory, Pennsylvania State College, State College, Pennsylvania.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Friday, April 24. The abtracts will not be printed. The titles of such papers as may be accepted will be announced on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule at the end of Session T.

Special programmes are being planned by the aides of the Local Committee for the **entertainment of the ladies.** There will be a special tour of the Bureau (men are not invited to take part!) with discussions and demonstrations; those who attend are asked to assemble in the Chemistry Lecture Room at 2:15 on Thursday afternoon. There will be a luncheon and fashion show at The Shoreham, in the Palladian Room, on Friday at 12:30. Other

events will be announced at the meeting. Reservations and general information may be obtained at the special Ladies' Registration Desk to be set up in the foyer of The Shoreham.

Prospective meetings of the Society are scheduled to be held in Rochester, New York, on June 18–20; in Albuquerque, New Mexico, on September 2–5; and in Chicago on November 27–28.

GENERAL RULES FOR PRESENTATION OF PAPERS

The time allowed for the oral presentation of a contributed paper is ten minutes at most. The time allowed for the presentation of each invited paper is stated in the Bulletin. Papers on the "supplementary programme" are allotted to the respective sessions indicated by footnote; but the respective Chairmen are empowered to cut the time allotted to each or any of such papers, or to read any by title.

Titles and abstracts of the papers contributed to the 1953 Washington meeting are printed hereinafter, and in exactly this form they will stand in a future issue of *The Physical Review*. Errata will be printed on an adjacent page of *The Physical Review* if received not later than **Friday, May fifteenth,** by Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. Do not send in the abstract marked with corrections: write out the corrections in the form "instead of . . . read. . . ." Do not add anything.

Speakers must retrieve their lantern slides before leaving the room in which the slides were shown. The Local Committee must not be burdened with the task of saving and returning them.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

This Is the Summons Card for the 1953 Summer Meeting in the West

This notice supplants the hitherto-customary summons card for the 1953 Summer Meeting in the West, to be held in Albuquerque, New Mexico, from Wednesday September 2 to Saturday September 5, 1953. The sessions will be held in the University of New Mexico. Invited papers are being bespoken in atmospheric physics, in cosmic rays, and in a great variety of topics in nuclear physics. The banquet will be held on Friday evening, and on Saturday there will be excursions to Los Alamos, to Socorro, and to the Santo Domingo Indian Pueblo.

Since a meeting in New Mexico is a novelty for our Society, more information about living quarters is given here than is customary for the Western meetings. Among hotels the Local Committee mentions the Alvarado, El Fidel, Franciscan, and Hilton, and among motor courts, the De Anza Motor Lodge, El Jardin Lodge, Tewa Motor Lodge, and Zia Lodge. Write to the one of your choice, with mention of the Society; and remember that a motor court will not hold a reservation later than 6:00 P.M. unless the maker of the reservation sends a check for one day's rental (it would be well to assume the same of hotels). Male members of the Society may reside in the Mesa Vista dormitory of the University, at $3 per person for a single room or at $2 per person for double occupancy of a room; to reserve here, write to Professor V. H. Regener at the University of New Mexico, Albuquerque, New Mexico. Make reservations as soon as you possibly can, and not later in any case than August 15th. Easterners should realize that eastbound trains will be in great demand at that time of year, just preceding Labor Day.

Deadline Will Be Wednesday, July First, at Los Angeles

Abstracts of contributed papers are to be sent to the address below (and NOT to the New York office), and must reach it not later than Wednesday, July first. Send two double-spaced typewritten copies, original and carbon (not two carbons!). Remember that an abstract must not be longer than 200 words or the equivalent thereof. In reckoning equivalence, a "display" formula (one that must occupy a line or more by itself) is an expensive luxury equated to 40 words; each line in a table counts as ten words, each footnote as 10 words. Confine each abstract to a single page.

J. KAPLAN, *Local Secretary for the Pacific Coast*
University of California
Los Angeles 24, California

EPITOME OF THE 1953 WASHINGTON MEETING

(Personal names are those of invited speakers. NBS stands for National Bureau of Standards)

Thursday Morning

A. Cosmic rays, I.: primary particles, showers. Shoreham, Terrace Room.
B. Magnetism. NBS, Materials and Testing.
C. Electron physics; Carlton. NBS, East Building.
CA. Elastic scattering of charged particles. Shoreham, West Ballroom.
D. Neutron physics, I. Wardman Park, Continental Room.
E. Aldrich, Libby, T. H. Johnson. Shoreham, Main Ballroom.
EA. Theoretical physics (nuclear structure). Wardman Park, Burgundy Room.

Thursday Afternoon

F. Cosmic rays, II.: stars, curious particles. Shoreham, Terrace Room.
FA. Ferroelectricity; metals. NBS, East Building.
G. Neutron physics, II. Wardman Park, Continental Room.
H. Theoretical physics (nuclear reactions and scattering). Wardman Park, Burgundy Room.
I. Divers topics in nuclear physics; Woodward, Fowler. Shoreham, Main Ballroom.
IA. Optical spectra; X-rays; Jen. Shoreham, West Ballroom.

Friday Morning

J. Atmospheric physics; Sanderson, Douglas, Kurzweg. Shoreham, Terrace Room.
JA. Theoretical physics (nuclear forces). Wardman Park. Burgundy Room.
K. Breckenridge, Vogel, Maxwell, Hogan. NBS, East Building.
KA. Reactions of transmutation and inelastic scattering, I. Shoreham, West Ballroom.
L. Business Session of Division of Chemical Physics; molecular and chemical physics. Wardman Park, Continental Room.
M. Vallarta, Leprince-Ringuet, Barnes, Tinlot. Shoreham, Main Ballroom.

Friday Afternoon

N. Mesons, I. Shoreham, Terrace Room.
NA. Fluid dynamics. NBS, Materials and Testing.
P. Solid-state and liquid-state physics. NBS, East Building.
PA. Reactions of transmutation and inelastic scattering, II. Shoreham, West Ballroom.
Q. Electronic and nuclear spins and moments. Wardman Park, Continental Room.
R. Bacher, Koch, Barkas. Shoreham, Main Ballroom.
RA. Schiff; theoretical physics (relativity and field theory). Wardman Park, Burgundy Room.

Friday Evening

Banquet of the American Physical Society. Shoreham, Terrace Room. Astin, Berkner.

Saturday Morning

S. Mesons, II (including some meson theory); Fry, Shapiro. Shoreham, Terrace Room.
SA. Pellam, Webber. Wardman Park, Continental Room.
T. Nuclear masses and fundamental constants; post-deadline papers. Shoreham, Main Ballroom.
U. Beta- and gamma-emitters, I. Wardman Park, Burgundy Room.
UA. Reactions of transmutation and inelastic scattering, III. Shoreham, West Ballroom.
V. Division of Fluid Dynamics: Chandrasekhar, Fultz, Charney. NBS, East Building.

Saturday Afternoon

VA. Symposium on hydrogen 3 and helium 3 reactions: Hemmendinger, Fremlin, Kundu, Chandrasekhar, Butler. Shoreham, Main Ballroom.
W. Cryogenics. Wardman Park, Burgundy Room.
WA. Semiconductors. NBS, East Building.
X. General physics; Biophysics, NBS, Materials and Testing.
XA. Apparatus of nuclear physics. Shoreham, Terrace Room.
Y. Beta- and gamma-emitters, II. Wardman Park, Continental Room.
Z. Platt, Segré, Silverman, Dyson. Shoreham, West Ballroom.

PROGRAMME

THURSDAY MORNING AT 10:00

Shoreham, Terrace Room

(BRUNO ROSSI presiding)

Cosmic Rays: Primary Particles, Showers

A1. High Altitude Cosmic-Ray Investigation by Means of a Čerenkov Counter. I. Instrumentation Details.* KINSEY ANDERSON AND JOHN R. WINCKLER, *University of Minnesota.*—Čerenkov counters of the type described recently[1,2] have been flown on a constant level balloon at 25 g/cm² atmospheric depth at geomagnetic latitude 40°. The detector was cycled through 0°, 60°, 90°, 120°, and 180° zenith positions and rotated in azimuth. The purpose of the experiment was to investigate the relativistic albedo flux and to compare the sea level and high altitude vertical pulse-height distributions. A height-to-time convertor was used for pulse transmission and was combined with other pressure and orientation data on a subcarrier telemetering system. The cosmic-ray particle was required to traverse 25 g in the detector to be registered by the Geiger telescope gate indicator. The accompanying Čerenkov pulse, if any, is also recorded on film. The factors affecting the pulse-height distribution from high energy sea-level mesons are photoelectron statistics and collision electrons above the Čerenkov threshold. At high altitudes the nucleon flux may also produce interactions in the Lucite block which can affect the distribution if relativistic particles emerge. One of the flights could record pulses up to a height equivalent to a relativistic nucleus of $Z=3$.

* This work was supported in part by a joint program of the U. S. Atomic Energy Commission and U. S. Office of Naval Research.
[1] J. R. Winckler and K. Anderson, Rev. Sci. Instr. **23**, 765 (1952).
[2] John Winckler, Phys. Rev. **87**, 241A (1952).

A2. High Altitude Cosmic-Ray Investigation by Means of a Čerenkov Counter. II. Experimental Results.* JOHN R. WINCKLER AND KINSEY ANDERSON, *University of Minnesota.*—A preliminary analysis of flight data indicates the following facts: (a) The pulse-height distribution in the vertical direction (0° zenith) shows a peak for singly charged particles which is considerably broader than for sea-level mesons. The tail does not show a clearly defined peak for $Z=2$ or $Z=3$ primary nuclei. (b) The pulse-height distribution at 180° zenith (inverted position) does not show a peak, but a residual of small pulses. The total number of upward events is 6 percent of the downward. The number of definitely relativistic upward events is about 3 percent of the downward. (c) At 60° zenith angle there is an azimuthal E–W asymmetry of about 30° for the total flux. The relativistic part of this (about 75 percent) shows approximately 40 percent asymmetry. This asymmetry for the total flux is about the same as observed previously at this latitude with counter telescopes. (d) At 90° zenith (horizontal) the total count shows no asymmetry. The relativistic part (for which direction of motion is established) shows a large E–W asymmetry, approximately 90 percent. (e) The detectable upward flux at 60° (telescope at 120° zenith) is about 5 percent of the total (down and up) at that angle and shows a maximum variation with azimuth of nearly 100 percent but apparently has two maxima and minima. The definitely relativistic upward flux is about 3 percent of the total.

* This work was supported in part by a joint program of the U. S. Atomic Energy Commission and U. S. Office of Naval Research.

A3. Time and Directional Study of Primary Heavy Nuclei.* G. W. ANDERSON, P. S. FREIER, AND J. E. NAUGLE, *University of Minnesota.*—The time dependence of the flux of primary heavy nuclei has been studied by means of nuclear emulsions exposed in plate movers at balloon altitudes. Two balloon flights were made, both from Minneapolis ($\lambda=55°$) and both during the period from sunset until early afternoon the next day. One of the balloons maintained an altitude of 18.5 g/cm² within ±1 g/cm² from 2330, July 31, 1952, until 1330 CST the following day. The number of nuclei in each of the two hour plate mover periods was constant within ±20 percent and exhibited no steady increase or decrease with time. The second flight, on August 28 and 29, 1952, was maintained at 30±3 g/cm² for 14 hours. An upper limit to the variation with time was found to be ±20 percent on this flight also. The emulsions in the first flight were kept in a constant orientation within ±15° with respect to magnetic north by means of a magnetic compass and compass follower system. The azimuthal distribution has been studied and found to be less than 12 percent asymmetric with the maximum from NE.

* Work supported in part by the joint program of the U. S. Atomic Energy Commission and U. S. Office of Naval Research.

A4. Intensity of Primary Protons and Alpha-Particles. L. R. DAVIS, H. M. CAULK, AND C. Y. JOHNSON, *Naval Research Laboratory.*—Two balloon flights at Minneapolis have resulted in an improved determination of the intensities of singly and doubly charged primary cosmic-ray particles. The particles were identified by ionization and range measurements, ionization being determined by three proportional counters and range by penetration of lead absorbers below the proportional counters. Secondary electrons and slow protons were identified and eliminated from the primary intensities. The resultant alpha-particle intensity exhibits an attenuation length of about 50 g/cm² in air. The vertical intensities, extrapolated to zero atmospheric depth, for singly and doubly charged particles are 0.21±0.01 and 0.034±0.004 (cm² sec sterad)⁻¹, respectively. The possibility exists that the alpha-intensity is high, because of a systematic error. The systematic error is no larger than 20 percent and ground calibrations will clarify the question.

A5. Heavy Nuclei in the Primary Cosmic Radiation.* T. H. STIX,† *Princeton University.*—Skyhook balloon flights at a geomagnetic latitude of 41°N made in April, 1952, carried a cloud chamber triggered by events causing ionization above a bias level in each of three proportional counters arranged in a telescope. The third counter was inside the cloud chamber. Pulse heights from each of the counters were recorded for all coincidence events, including those accompanied by a cloud chamber picture. Accompanying discharges in out-of-line Geiger tubes were also indicated. The statistics from the proportional counter telescope will be correlated with the cloud chamber information, and results given in terms of the charge spectrum of the incident primary radiation and of time radiations in components of this spectrum.

* Supported by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
† U. S. Atomic Energy Commission Predoctoral Fellow.

A6. Time Variation of Cosmic-Ray Heavy Nuclei. VICTOR H. YNGVE AND MARCEL SCHEIN, *University of Chicago.*—Two 4×4 Ilford G-5 photographic emulsions in contact were exposed to the cosmic radiation in such a way that one plate was moved slowly and uniformly with respect to the other.[1] By this technique it is possible to determine definitely the time at which heavy nuclei passed through the plates. The plates were exposed above 90 000 feet June 4, 1952, for 8 hours during the day. Reliable altitude data are available, making possible corrections for its rather small fluctuations during the 8 hours. 964 heavy nuclei with more than 10 delta-rays per 100 microns, corresponding to Z greater than about 10, were traced through and their time of passage measured. The data have been divided into several time intervals, and the intensity in the different intervals will be compared. The new developments in the technique will be described and the experimental results will be discussed in connection with previously observed time variations of heavy nuclei.[1–3]

[1] J. J. Lord and Marcel Schein, Phys. Rev. **80**, 304 (1950).
[2] Freier, Ney, Naugle, and Anderson, Phys. Rev. **79**, 206 (1950).
[3] E. P. Ney and D. M. Thon, Phys. Rev. **81**, 1069 (1951).

A7. Cloud-Chamber Study of Particles in Primary Cosmic Radiation.* FRANK B. MCDONALD,† *University of Minnesota.*—In order to study the flux and interactions of the primary cosmic radiation in the range $z=2$, 3, 4, and 5, a cloud chamber triggered by a crystal (NaI) scintillation counter has been developed for use at balloon altitudes. A Geiger-counter telescope defines a trajectory through the scintillation counter and the center of the illuminated region of the cloud chamber. The output of the scintillation counter is amplified and put through a one-channel discriminator which, if gated by the Geiger-counter telescope, triggers the cloud chamber. Thus, it is possible to observe, in the cloud-chamber, particles in a given ionization interval. The cloud chamber has an illuminated depth of 10 cm and has four 1.5 cm thick absorber plates—two carbon and two lead. These plates not only aid in the identification of slow secondaries which initiate an expansion but also make it possible to study the interaction of the primaries in various types of materials. Results of recent flights for the purpose of studying the primary α-flux with this apparatus at a geomagnetic latitude of 41°N and at an altitude of 84 000 feet will be discussed. Typical cloud-chamber pictures obtained at altitude will be shown. Preliminary results indicate the flux values found for the α's seem to be significantly lower than those reported by other observers.

* This research supported by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
† Atomic Energy Commission Predoctoral Fellow.

A8. Remarks on The Cosmic-Ray Albedo.* S. B. TREIMAN, *Princeton University.*—It has long been recognized that part of the albedo radiation leaving the earth may bend in the earth's magnetic field and return from overhead. The Stoermer approximation is used to set a lower limit on the number of returning albedo particles which appear in the primary cosmic radiation. These particles differ from true primaries in that they can arrive with energies below the cutoff at any latitude. It is estimated that an appreciable fraction of the "primary" radiation at the equator may consist of albedo particles. Although the albedo leaves the earth preferentially at large zenith angles, this strong angular dependence may be washed out in the returning radiation because of deflection in the earth's field. This appears to be consistent with recent observations of returning albedo radiation.[1] It is also pointed out that albedo radiation, from the earth and from other heavenly bodies, may contribute to the filling of trapped orbits in the field of the postulated solar magnetic dipole.[2]

* Supported by the U. S. Atomic Energy Commission and U. S. Office of Naval Research.
[1] Perlow, Davis, Kissinger, and Shipman, Phys. Rev. **88**, 321 (1952).
[2] Kane, Shanley, and Wheeler, Revs. Modern Phys. **21**, 51 (1949).

A9. A Cloud-Chamber Investigation of Nuclear Interactions.* N. R. WHETTEN, R. S. PRESTON, R. V. ADAMS,† AND R. W. WALKER, *Yale University.*—A magnet cloud chamber has been constructed at Yale University and installed in a trailer laboratory. The trailer laboratory was transported to Climax, Colorado (elevation 11 200 feet) and operated during the late fall of 1952. The cloud chamber is a double chamber, with dimensions of 25 cm×25 cm×8 cm illuminated region. This double chamber construction enables a proportional counter, or absorbing materials, to be placed between the two chambers. A 6-ton electromagnetic produces a magnetic field of 8000 gauss across the chamber. Stereoscopic photographs are taken through a large hole in one of the pole pieces. The cloud chamber was expanded by a triggering system which selected penetrating showers. Two thousand photographs were obtained. Twenty percent of 1100 photographs of good quality contained events involving two or more more penetrating particles. Eight V particles were observed.

* Assisted by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
† Now at Mt. Holyoke College, South Hadley, Massachusetts.

A10. Emulsion Chamber Studies of High Energy Cosmic-Ray Interactions.* J. J. LORD, *University of Washington.*—An emulsion chamber experiment has been designed to study high energy nuclear interactions. Thirty-six 2-in.×8-in. glass backed 600-micron thick photographic emulsions were arranged in a stack with adjacent emulsions in contact. With the emulsion surfaces vertical, this stack was placed directly over a lead-emulsion chamber. The chamber consisted of a sandwich of 18 horizontal lead plates each ¼ in. in thickness and an equivalent number of 400-micron thick 4-in.×8-in. photographic plates. This arrangement was flown by balloon from Minnesota in December, 1952. The plates were exposed for about 5 hours at elevations between 90 000 and 95 000 feet. In a preliminary study of some 60 high energy showers, one originating in the outer container consisted of a core of 3 high energy pairs within a radius of 2 microns and 5 other other minimum ionization tracks within a radius of 10 microns. After traversing 31 plates of the upper stack in a distance of 7 cm, this core consisted of about 50 tracks within a radius of 15 microns. The shower energy (estimated as about 10^{13} ev) and development are in agreement with theory. Additional analyses of high energy showers will be given.

* Assisted by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.

A11. Time Delays in Air Showers.* P. BASSI, G. CLARK, AND B. ROSSI, *M.I.T.*—We are investigating the possibility of determining the orientation of air shower cores by measuring the delays between widely spaced counters. Large liquid scintillation counters are being used with fast electronic equipment to detect air showers and to record the times of arrival of particles at the counters. Showers are detected by threefold coincidences between counters with a resolving time of 3×10^{-7} sec. The pulses from the counters are spaced in time with respect to one another by fixed delay lines and are then displayed on the vertical deflection plates of a fast oscillograph. Delays between pulses can be measured to within 5×10^{-9} sec. We have measured delays in the range $(0.5-10)\times10^{-8}$ sec. At a given instant most particles in an air shower are concentrated in a shower "front." This is a segment of a thin shell whose axis of symmetry is the shower core. We shall present experimental data that we interpret in terms of the thickness and curvature of the front and the orientation of the core. Preliminary results indicate that the rms delay between the first pulses from two counters of sensitive area 0.06 m² placed 3 m apart is about 1×10^{-8} sec for showers of average density 16 particles/m². The observed effect of a

thick abosrber placed over one of the detectors will be discussed.

* Supported in part by the joint program of U. S. Office of Naval Research and Atomic Energy Commission.

A12. Altitude Variation and Transition Effects of Air Showers.* O. PICCIONI AND R. L. COOL, *Brookhaven National Laboratory.*—Air showers of 10^4 electrons or more have been studied at various altitudes up to 35 000 feet. The particles present in the showers, which produce nuclear interactions, were detected and their number compared with electron electron densities. As previously communicated, this "N component" remains closely proportional to the electron component when the altitude is changed from sea level to 11 000 feet. Above that level, the electrons increase less rapidly than N particles, the more so the higher the altitude. At 35 000 feet, the frequency of showers containing at least one N particle is about 200 times as great as at sea level. Transition effects at the cores of showers of about 10^4 particles have been investigated at 11 000 feet with Pb (up to 15 rad. lengths) and carbon (64 g cm^{-2}). The introduction of the carbon (2 meter$\times$2 meter) between two layers of 1.5-in. Pb, in a region approximately defined by 2 core selectors has no effect ($<$10 percent) on the number of electrons underneath the lowest Pb layer. The transition effect with Pb absorber reaches a factor 3 at 6 rad. lengths which is less than expected. This seems to indicate that each shower has a penetration appreciably less than currently assumed.

* Research done under contract with U. S. Atomic Energy Commission.

A13. The Mean Free Path for Shower Production by High Energy π-Mesons.* FRITZ E. FROEHLICH AND KURT SITTE, *Syracuse University.*—Penetrating showers of various multiplicities were recorded under lead absorbers of 0, 200, 440, and 660 g/cm^2 thickness. These top absorbers were subdivided into three layers, and a counter tray placed under each of them. By strictly demanding that in each of these trays only one counter is struck, interactions in the top absorber are efficiently eliminated even for the largest thickness used. In this way, a possible difference in the mean free path for shower production of the two main components of the N radiation, protons and π-mesons, can be established since under the thick absorber the component with the longer mean free path is "enriched". The data obtained show that even for showers of high multiplicity the attenuation decreases with increasing absorber thickness, indicating a mean free path for shower production in lead by π-mesons of at least 500 g/cm^2. This result is supported by the observation of a barometer coefficient of about 7 percent for the heavily shielded showers, well below the value of 11.7 percent characteristic for the proton component.

* Supported by the Air Force Cambridge Research Center.

A14. Development of Extensive Showers in the Atmosphere.* KURT SITTE AND DON L. STIERWALT, *Syracuse University,* AND IRVING L. KOFSKY, *Smith College.*—A cloud chamber fitted with eight 1-in. carbon plates and a hodoscope of 118 counters arranged in ten trays were operated at Mt. Evans (altitude 4300 m) in order to study the electron distribution in showers of various age. Six trays were placed beneath the cloud chamber, separated by $\frac{1}{2}$-in. lead plates, and four trays were located at distances from 2 to 8 m from the chamber. An additional tray placed directly above the cloud chamber which was triggered only by events of sufficiently high particle density made it possible to select showers whose cores struck near the central chamber-hodoscope arrangement. By studying the transition effect in the lead plates, the total incident energy and the energy spectrum near the core of the shower can be observed, and from them an age classification is obtained. The lateral distribution is recorded by the "outside" hodoscope trays. The preliminary results indicate a lateral spread well in excess of the data derived for single-electron cascades.

* Supported in part by the U. S. Atomic Energy Commission.

A15. Energy Spectra of Cosmic-Ray Photons and Electrons from Plastic Scintillation Counter Measurements.* C. N. CHOU, *University of Chicago.*—A new method of measuring high energy photons and electrons is reported. Using an experimental arrangement consisting of G-M counters and scintillation counters with large plastic scintillators, the number *vs* size distribution of cosmic-ray showers produced by photons and electrons in a lead block of one inch thickness was measured. From the results of shower theory, the energy spectra of cosmic-ray photons and electrons at Chicago (600 ft above sea level and 51°N geomagnetic latitude) were deduced. The results of the present investigation show that in the energy range of 0.3$-$2.0 Bev the differential energy distributions can be represented by a power law of the form e^{-s}, with $s=2.71\pm0.13$ and $s=2.81\pm0.13$ for the photon and electron components, respectively. The exponent s decreases considerably at energies below 0.2 Bev. An essential part of this investigation is to provide a suitable means of measuring the energies of energetic γ-rays or electrons, or the energy distribution of energetic γ-rays or electrons. The results show that scintillation counter arrangements consisting of large plastic scintillators are suitable instruments for these purposes. This method could also be applied to energy measurements of photons and electrons from high energy accelerators.

* Supported by the joint program of U. S. Atomic Energy Commission and U. S. Office of Naval Research.

THURSDAY MORNING AT 10:00

NBS, Materials and Testing

(J. H. VAN VLECK presiding)

Magnetism

B1. Calculation of the Diamagnetic and Paramagnetic Susceptibility of N_2. J. V. BONET AND A. V. BUSHKOVITCH, *St. Louis University.*—The only complete theoretical calculation of the magnetic susceptibility of a diatomic gas carried out so far appears to be that of H_2 by Van Vleck and Frank. We have attempted to calculate both the diamagnetic and paramagnetic term in the susceptibility of N_2 using the statistical method of Thomas and Fermi corrected for exchange effects. A statistical electron density of N_2 corrected for exchange is used to evaluate the integral $\int \rho r^2 dv$, which defines the mean square electronic position of the entire molecule appearing in the diamagnetic term. A statistical distribution function of the

square electronic angular momentum of the molecule is derived, and the mean square electronic angular momentum of the molecule appearing in the paramagnetic term is defined in terms of the distribution function. This procedure leads to a result which, although 1.86 times larger than the observed value, still is fully as good as similar calculations for atoms. Statistical calculations along these lines of the susceptibility of diatomic gases considerably heavier than nitrogen (such as chlorine, bromine, iodine) are in progress and will surely yield results in much closer agreement with experiments.

B2. A Free Energy Model for the Hysteresis Loop. ARTHUR L. LOEB,* *M.I.T.*—The free energy of ferromagnetic substances can be expressed as an even polynomial in the magnetization[1] in the absence of an external field, including exchange, Fermi, magnetostatic and magnetostrictive, and entropy terms. Below the Curie point there are two minima, separated by a maximum at zero magnetization. An external field introduces a linear term so that the free energies corresponding to the two relative minima are different. The maximum shifts from zero magnetization toward the relative minimum with higher free energy; it presents an energy barrier that prevents transitions from the higher relative minimum to the lower one until the external field is so high that the maximum and relative minimum merge into a point of inflection. The value of the field where this happens is the coercivity. Relations are derived between coercivity, magnetization, and Curie temperature, and from hysteresis loops measured at different temperatures an estimate of magnetization entropy is obtained.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with M.I.T.
[1] Slater, *Quantum Theory of Matter*, first edition, p. 515.

B3. Nucleation Centers for Domains of Reverse Magnetization.* J. B. GOODENOUGH, *M.I.T.*—If a field strength which saturates a ferromagnetic material is reduced to zero and reversed, the induction in the sample will be reversed only after domains of reverse magnetization are created and the resulting 180° Bloch walls are moved until they anihilate one another. Inclusions, grain boundaries, and crystalline surfaces are analyzed as lattice imperfections which could act as nucleating centers for the reverse domains. It is concluded that the grain boundaries are the most probable nucleation centers in polycrystalline materials. A nucleating field strength H_n is defined. The criterion for a square-loop material is $H_n \geq H_c$. This model shows how H_n is increased by the alignment of the axes of easy magnetization from grain to grain. It also shows that materials of low saturation magnetization and high anisotropy constant may have square minor loops without alignment of the easy magnetization directions. The hysteresis is the relation between stress and magnetization with constant field strength is also explained by this model.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with M.I.T.

B4. Magnetization Reversal of Square-Loop Polycrystalline Materials by Domain Growth.* NORMAN MENYUK, *M.I.T.*—Magnetization reversal of square-loop polycrystalline materials appears to depend primarily upon the growth of domains of reverse magnetization. Triangular domain patterns have been seen,[1] and are considered two-dimensional representations of conical domains. The reversal rate pattern which has been observed is explained by the growth of these domains. An approximation of the Bloch walls as cylindrical and an extension of existing theory to Bloch walls of this shape leads to a determination of $(H-H_0)\tau$ in terms of various parameters of the material, where τ is the time required for magnetization reversal, H is the applied field, and H_0 the threshold value of irreversible domain growth. The switching coefficient S_w, where $S_w=(H-H_0)\tau$ should be constant for a particular material. This has been verified experimentally for a General Ceramic ferrite core and a grain oriented thin-ribbon 4–79 Molybdenum Permalloy core. The experimental values of S_w and H_0 obtained were in good agreement with expected values.

* The research in this document was supported jointly by the Army, Navy and Air Force under contract with M.I.T.
[1] C. Kittel, Revs. Modern Phys. 21, 548 (1949).

B5. The Faraday Effect in Metals at Microwave Frequencies. LEO M. SILBER AND FOSTER F. RIEKE, *Purdue University*.—The Faraday effect has been observed in thin films of iron at 9200 Mc/sec. The largest rotation observed was $\frac{3}{4}$ degree. The rotation is proportional to magnetization of the film up to the highest flux densities obtainable in this apparatus: −15 000 gauss. The rotation is also proportional to the film thickness, within the accuracy of measurement of the thickness. Thicknesses from 2×10^{-6} to 1×10^{-5} cm were tested. It has also been observed that on transmission through the film the wave becomes elliptically polarized. The observed rotation and axis ratio are compared to the predictions of the theory of Hogan.[1] The theory gives good agreement with experimental results for rotation and axis ratio, but it yields too small a value for the total attenuation of the film. The Faraday rotation has not been observed in nickel, though the theory predicts a measurable rotation. Failure to observe it may be due to strain in the films.

[1] C. L. Hogan, Bell System Tech. J. 31, 1 (1952).

B6. Single Crystal Magnetostriction Constants of Iron-Cobalt Alloys.* HELEN M. A. URQUHART, *Carnegie Institute of Technology*.—The single crystal magnetostriction constants of a series of iron-cobalt alloys were measured using the strain gauge method.[1] The crystals (kindly loaned by Professor McKeehan) were in the form of oblate spheroids approximately 3 mm in diameter and 0.3 mm in thickness. The error in the measurement is of the order of 7 percent; it is due primarily to the uncertainty in determining the gauge direction relative to the principal crystal axes. The error due to neglecting all but the first two constants in Becker's formula is small compared to this. The polycrystalline saturation magnetostriction values calculated using the relation $\lambda_s=(2\lambda_{100}+3\lambda_{111})/5$ and our constants are in excellent agreement with observed values from polycrystalline material. Curves of λ_{100} and λ_{111} as a function of cobalt content have been obtained which, when extrapolated to pure iron, give good agreement with previous data and show λ_{111} to be negative below 36 percent cobalt. λ_{100} is found to be positive in the entire range of composition and appears to reach a maximum near 40 percent cobalt, which is where the saturation moment is a maximum and the crystalline anisotropy is zero.

* Supported by U. S. Office of Naval Research and an Allegheny-Ludlum Fellowship.
[1] J. E. Goldman, Phys. Rev. 72, 592 (1947); J. Phys. 12, 471 (1951).

B7. Magnetostriction in Iron-Cobalt Alloys.* K. AZUMI,† *Carnegie Institute of Technology* (introduced by J. E. Goldman).—Measurements have been made of the magnetostriction of several polycrystalline iron-cobalt alloys as a function of applied field. Using the strain gauge method, measurements were made in the three orthogonal directions of a 2.2-cm cube. In this way errors due to nonrandomness in the domain and crystal orientation are eliminated. The results of our measurements will be compared with those of Masiyama and of Williams[1] and with the values calculated from the data of Urquhart.[2] A low field maximum in the magnetostriction of a 32 percent alloy further confirms the latter's conclusion that λ_{111} is negative in this composition range. The results in all cases are in very good agreement. An attempt to calculate the single crystal data from our polycrystalline measurements, based on a method suggested by Bates and Lee,[3] gave good

agreement with Urquhart's data at some compositions, but its general applicability in all cases is uncertain.

* Supported by the U. S. Office of Naval Research.
† Post-doctoral fellow on leave from Transportation Research Institute, Tokyo, Japan.
[1] Y. Masiyama, Sci. Rep. Tohoku Imp. Univ. **21**, 394 (1932); S. R. Williams, Rev. Sci. Instr. **3**, 675 (1932).
[2] H. M. A. Urquhart (previous abstract).
[3] L. F. Bates (private communication to Professor J. E. Goldman).

B8. Antiferromagnetostriction. HELEN M. A. URQUHART AND J. E. GOLDMAN, *Carnegie Institute of Technology.*—Consideration of the dipole-dipole interaction energy in an antiferromagnetic lattice with low magnetic symmetry indicates that a spontaneous distortion of the lattice analogous to the spontaneous magnetostriction in ferromagnets should manifest itself. Unlike the ferromagnetic case, the macroscopic behavior would be little affected by an applied field since the spin system in an antiferromagnet is unaffected by fields of ordinary magnitudes. In the case of rhombohedral α-Fe_2O_3, however, where Shull finds a change in sign of the crystal anisotropy near -20°C, i.e., the orientation of the moments changes from the long rhombohedral diagonal to a direction perpendicular thereto, the magnetostatic energy would be minimized in an external field is the spin system could set itself perpendicular to the field at temperatures near the transition where the anisotropy is low. We have measured the lattice distortion accompanying this shift in spin axis using resistance strain gauges on a natural single crystal of α-hematite. The magnitude of the distortion, which we have termed antiferromagnetostriction, is comparable with magnetostriction in ordinary ferromagnetic materials. By noting the variation of the distortion with rotation of the crystal and as a function of temperature, we have been able to establish accurately the transition temperature which appears to be a function of applied field, and which is not unexpected if the magnetic energy is comparable with the anisotropy energy.

B9. Neutron Diffraction Study of Antiferromagnetic Structure of Pyrrhotite, FeS_x.—S. S. SIDHU AND DAVID MENEGHETTI, *Argonne National Laboratory.*—X-ray and neutron diffraction data obtained for a polycrystalline sample of natural pyrrhotite show that this compound has the nickel arsenide type structure with lattice constants, $a_0=3.440$A, $c_0=5.728$A, and $c=1.665$. Its differential thermal analysis shows that there is a major reversible endotherm starting near 300°C and peaking at about 325–330°C. The neutron diffraction pattern contains antiferromagnetic reflections below this temperature. The positions and the relative intensities of these reflections have been used to determine the size of the magnetic unit cell and the atomic magnetic moment orientations with respect to crystallographic axes. The temperature dependence of the intensities of antiferromagnetic reflections have been studied.

B10. A Neutron Diffraction Study of BiMn Alloy.* B. W. ROBERTS, *General Electric Research Laboratory.*—The 1:1 atomic ratio alloy of BiMn was grown from loose powders and compressed briquets in magnetic fields greater than 2000 gauss at 315°C. Yields of roughly two-thirds BiMn were obtained. The resulting bars were highly oriented, with the 00.2 neutron reflection giving a half-width of 5°. The magnetic field prevented the density segregation of the Mn and molten Bi. Neutron diffraction intensities taken on powders at 25°C show the magnetic moments to be aligned along the C_0 axis with a magnitude close to four Bohr magnetons (Mn^{+++}). By following the intensity of the 10.0 reflection from a highly oriented bar of BiMn, the temperature hysteresis at the 360°C Curie temperature was found in the magnetic scattering. Shifts in the 00.2 scattering angle indicate the hysteresis corresponds with an abrupt contraction of the C_0 axis. The same bar was studied above 360°C and showed no evidence for an antiferromagnetic structure in the low temperature unit cell.

* Research carried out at the Brookhaven National Laboratory pile.

B11. The Magnetic Susceptibility of Wurster's Blue Between 65° and 356°K.* N. ELLIOTT AND M. WOLFSBERG.—The magnetic susceptibility of Wurster's Blue perchlorate was measured on a Gouy balance and found to be qualitatively similar to the susceptibility of an antiferromagnetic material. The maximum susceptibility occurred at 180°K. Above this temperature the Weiss-Curie formula satisfied the data. The magnetic moment corresponded closely to that calculated for a single electron spin. The results of the susceptibility measurements are compatible with the paramagnetic resonance measurements originally made by Dr. S. I. Weissman of Washington University.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.

B12. Magnetic Saturation and Apparent Molecular Fields of $MnCl_2\cdot 4H_2O$. WARREN E. HENRY, *Naval Research Laboratory.*—The applicability of the free spin Brillouin function for paramagnetic ions up to over 99.5 percent saturation has been demonstrated by previous measurements[1] on substances in which the interionic interaction is negligible. This makes possible an investigation of the molecular fields associated with antiferromagnetism through nonsuperposition of magnetic isotherms when M is plotted against H/T, H being the applied magnetic field. $MnCl_2\cdot 4H_2O$ (Néel temperature $=1.6$°K) was chosen to minimize experimental difficulties. Magnetic moment measurements, to practical saturation, were performed in the temperature range 1.3–4.2°K. By attributing the departure of the moment (plotted against H/T) from a Brillouin function to a molecular field[2] contribution, one obtains a ratio between this contribution and the moment which is a constant to within ± 10 percent over a wide range of H/T. Extrapolation of this contribution to saturation yields $\sim$14 000 gauss for the apparent molecular field. The use of a simple model[3] enables one to calculate an energy density (associated with an antiferromagnetic exchange integral) of $\sim 10^8$ ergs/cm.[3]

[1] W. E. Henry, Phys. Rev. **88**, 559 (1952).
[2] J. H. Van Vleck, J. Chem. Phys. **9**, 85 (1941); L. Néel, Ann. phys. **17**, 64 (1932); **5**, 256 (1936); F. Bitter, Phys. Rev. **54**, 79 (1937).
[3] J. H. Van Vleck, J. phys. et radium **12**, 282 (1951).

B13. Reversible Susceptibility in Ferrimagnetic Materials.* D. M. GRIMES, L. W. ORR, and M. H. WINSNES, *University of Michigan.*—The low frequency reversible susceptibility for both parallel and transverse biasing fields has been measured on several samples of ferrite materials. Qualitative agreement with the following parametric expressions was found:

$$\frac{J}{J_s}=f(\eta);\quad \frac{\chi_{rl}}{\chi_0}=3f'(\eta);\quad \frac{\chi_{rp}}{\chi_0}=\frac{3f(\eta)}{\eta},$$

where

$$f(\eta)=\coth\eta-(1/\eta),$$

the Langevin function. The expression for the parallel reversible susceptibility was first derived by Brown[1-2] using a statistical method based on the Heisenberg model, and later[4] on a more realistic model. Both models assume isotropic domains. The expression for the transverse reversible susceptibility is based on a simple extension of the parallel formula.

* Supported by the U. S. Army Signal Corps.
[1] William Fuller Brown, Jr., Phys. Rev. **52**, 325 (1937).
[2] William Fuller Brown, Jr., Phys. Rev. **53**, 482 (1938).
[3] William Fuller Brown, Jr., Phys. Rev. **54**, 279 (1938).
[4] William Fuller Brown, Jr., Phys. Rev. **55**, 568 (1939).

THURSDAY MORNING AT 10:00

NBS, East Building

(J. B. JOHNSON presiding)

Electron Physics

C1. Stark Shift and Broadening due to Electrons.* M. BARANGER, *Cornell University.*—The effect of electrons on the line shape in argon is calculated, for ion densities ranging from 10^{17} to 10^{18} cm^{-3} and temperatures of the order of 12 000°K. With these conditions, the classical approximation is a suitable one, that is, the line shape is obtained by Fourier analyzing the phase factor $\exp(-ik\int F^2dt)$, where k is the Stark constant for the state considered and F the electric field, which is a function of time. Owing to the high velocity of the electrons, it is permissible to replace this continuous phase variation by a series of discontinuous changes, there being one such discontinuous change for each passing electron. Because most electrons give rise to only a small phase change, one obtains a shift in addition to the broadening. This shift is several times larger than the one given by the static theory of Holtsmark. Agreement with the experiments of Kantrowitz[1] is satisfactory.

* Supported by the U. S. Office of Naval Research.

[1] A. Kantrowitz, Bull. Am. Phys. Soc. **28**, 1 (1953).

C2. Hall Effect in Flowing Ion Clouds.* B. E. CLOTFELTER AND R. G. FOWLER, *University of Oklahoma.*—The shock wave and flow of ionized gas produced by discharging a condenser through gas at low pressure and allowing the heated gas to expand have been investigated by the Hall effect. Magnetic fields were applied normal to the direction of flow and to the line joining two probes placed at various positions along the ion flow. The signal from the probes was passed through a difference amplifier and displayed on an oscilloscope. With the probes connected to high impedance, their potential depends only upon the applied magnetic field and the velocity of flow of the ionized gas, giving velocity profile in time. When the probes are shunted to ground by low resistances, the potentials measured depend upon the plasma resistance. Plasma resistance should be related to ion concentrations and/or temperatures, but the standard mobility theory yields a relation in general disagreement with experiment, as does a theory based upon electron-proton collision cross sections coupled with elastic-solid-sphere mobility theory. The variation of resistance with position is interpreted as indicating the failure under the conditions of this discharge of Holtsmark's method of determining ion concentrations by Stark broadening.

* Research supported by the U. S. Office of Naval Research.

C3. Photoionization of Nitric Oxide. K. WATANABE, FREDERICK MARMO, AND EDWARD C. Y. INN, *Geophysics Research Directorate.*—Ionization cross section of nitric oxide was measured in the spectral region 1070–1345A, at intervals one to five angstroms apart, using a vacuum monochromator (band width 0.85A), an absorption cell with collectors, and a detector calibrated[1] against a thermocouple. As the spectrum was scanned, the onset of photoionization occurred abruptly at 1345A or 9.20±0.02 ev, which appears to be the first ionization potential of NO. This energy is somewhat lower than the value, 9.4±0.2 ev, obtained by the electron impact method.[2] Over most of the spectral region, the ionization cross section represented a rather high fraction of the total absorption cross section. For example, at Lyman alpha the former was about 1.5×10^{-18} cm^2 and the latter 2.5×10^{18} cm^{-2}. The application of these data and the absorption cross section of oxygen to the formation of the D layer[3] will be indicated.

[1] K. Watanabe and E. C. Y. Inn, J. Opt. Soc. Am. **43**, 32 (1953).
[2] H. D. Hagstrum, Revs. Modern Phys. **23**, 185 (1951).
[3] D. R. Bates and M. J. Seaton, Proc. Phys. Soc. (London) **B63**, 129 1950).

C4. The Ionization and Dissociation of Nitromethane by Electron Impact.* R. J. KANDEL, *Los Alamos Scientific Laboratory.*—The appearance potentials of seventeen ions from nitromethane were determined on a Consolidated Engineering Corporation Model 21–103 Mass Spectrometer by the vanishing-current method. The metastable suppressor on the instrument was used to determine when ions were formed with excess kinetic energy and to estimate the amount. The carbon-nitrogen bond dissociation energy was found to be 2.5 volts, in agreement with calorimetric values. The ionization potential of NO_2 was found to be 10.0 volts, 2.3 volts less than the value reported elsewhere.[1] Processes in the spectrometer resulting in the fragmentation of the nitrogen-oxygen bond appear to be accompanied by an exothermal rearrangement of the nitrosomethane, possibly to formaldoxime. Otherwise the bond dissociation energy of the nitrogen-oxygen bond would be less than 1.0 volt. This would leave unexplained the considerably higher value of 2.3 volts reported for the activation energy of decomposition of this molecule.[2]

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] W. C. Price and D. M. Simpson, Trans. Faraday Soc. **37**, 106 (1941).
[2] T. L. Cottrell and T. J. Reid, J. Chem. Phys. **18**, 1306 (1950).

C5. Natural Lifetime of the Cadmium 5^3P_1 State. C. G. MATLAND, *Westinghouse Research Laboratories.*—A direct measurement of the lifetime of the 5^3P_1 state of cadmium has been made. The transition from this excited state to the ground state gives rise to the 3261A resonance line of cadmium. The experimental techniques used were those developed for the measurement of imprisonment of resonance radiation.[1] Cadmium vapor, enclosed in a quartz tube, was excited by 3261A radiation. After the excitation was cut off, the decay time of radiation escaping from the vapor was observed. In the present experiment, for vapor densities greater than 10^{13} atoms/cc, the decay time was found to depend on the density, as predicted by imprisonment theory.[2] For vapor densities below 10^{13} atoms/cc the decay time becomes constant, indicating the absence of imprisonment effects. Under these circumstances the measured decay time is equal to the natural lifetime. Measurements made over the density range 10^{12}–10^{13} atoms/cc yield a value of 2.05±.05 microseconds for the lifetime of the Cd(5^3P_1) state. This value is in agreement with the result of King and Stockbarger,[3] but it is 15 percent lower than the generally accepted value.

[1] Alpert, McCoubrey, and Holstein, Phys. Rev. **76**, 1257 (1949).
[2] T. Holstein, Phys. Rev. **72**, 1212 (1947).
[3] R. B. King and E. C. Stockbarger, Astrophys. J. **91**, 488 (1940).

C6. Metastable Atoms in the Afterglow of a Low Pressure Helium Discharge. ARTHUR V. PHELPS, *Westinghouse Research Laboratories.*—Microwave and optical absorption techniques have been used to make simultaneous measurements of the electron and metastable atom densities in the afterglow of a low pressure helium discharge. The measurements of the electron and metastable atom densities show that the rise of the electron density during the afterglow is the result of the production of ions and electrons by collisions between pairs of metastable atoms as proposed by Biondi.[1] The time variation of the triplet metastable density shows that there is a production of triplet metastable atoms as a result of collisions between singlet metastable atoms and electrons.

[1] M. A. Biondi, Phys. Rev. **88**, 660 (1952)

C7. Diffusion Cooling of Electrons in Ionized Gases. MANFRED A. BIONDI, *Westinghouse Research Laboratories.*—Measurements of the loss of electrons in neon and argon afterglows yield unexpectedly low values for the ambipolar diffusion coefficient, D_a, which is given by $D_a \simeq D_+(1+u_e/u_+)$, where D_+ is the ionic diffusion coefficient; u_e and u_+ are the average energies of the electrons and ions, respectively. The low values of $D_a(<2D_+)$ result from the condition $u_e<u_+=u_{gas}$. The reduction in average electron energy is caused by "diffusion cooling," i.e., the loss of fast electrons from the distribution by their diffusion to the walls of the container. In gases such as neon and argon, which exhibit very small elastic collision cross sections for slow electrons, elastic collisions occur too infrequently to compensate completely for this energy loss, and hence u_e drops appreciably below u_{gas}. Measurements of this effect over the range $0.2u_{gas} \leq u_e \leq u_{gas}$ agree with qualitative theoretical predictions.

C8. Electron Interferometry. L. MARTON, J. AROL SIMPSON, AND J. A. SUDDETH, *National Bureau of Standards.*—The interferometer, operating with an electron beam and briefly announced at last years' annual meeting[1] has been constructed and tested. The instrument belongs in the category of "wide-beam" interferometers; beam splitting is achieved by amplitude splitting as in the Mach-Zehnder type of instrument of light optics. In absence of "true" reflexion for electrons, diffraction on thin crystal lamellae was chosen as the beam splitting process. A peculiarity of this kind of beam splitter is that it produces an "achromatic" instrument, that is, its fringe system is independent of the spectral composition of the radiation emerging from the source. The performance of the instrument is in good agreement with predictions based on light optical analogies. Further plans call for improvements in the preparation of the beam splitting crystals, for better mechanical stability of the instrument and for an investigation of other interfoerometric systems. Particular interest is attached to nonachromatic interferometers since these are of importance for application to interference spectroscopy and for coherence experiments. The present version of the instrument with some modifications may lend itself to h/m determination, to field gradient measurements, and to other experiments.

[1] L. Marton, Phys. Rev. **86**, 585 (1952), Abstract D3; J. A. Simpson, Phys. Rev. **86**, 585 (1952), Abstract D4.

C9. The Construction and Operation of an Electron Interferometer. J. A. SUDDETH, L. MARTON, AND J. AROL SIMPSON, *National Bureau of Standards.*—The interferometer discussed in the preceeding abstract uses three copper single crystals, spaced 35 mm apart, as diffractors. These crystals, 3.2 mm in diameter and approximately 100A thick, were grown by a process known as epitaxy. They are supported by 20 mesh/mm copper electroplated screens. The crystals are mounted in a manner to allow the following motions: rotation of each crystal about the axis of the instrument and translation of one crystal along the same axis. A movable aperture is provided to allow either of the two interfering beams to be cut out at will or to allow both to pass. The interferometer is mounted in place of the object chamber of an electron microscope, the microscope providing the electron source and the viewing system. The illuminating and viewing systems are restricted to angular apertures of 10^{-3} radian. The microscope components are aligned in the usual manner, but the crystals of the interferometer must be aligned by photographic techniques because of the low intensity.

C10. Observations in an Electron Interferometer and Their Interpretation.* J. AROL SIMPSON, J. A. SUDDETH, AND L. MARTON, *National Bureau of Standards.*—The fringe system produced by the electron interferometer described in the preceding abstracts will be shown on slides. The appearance of the fringes may be changed at will by changes in the (electron) optical path. Such changes may be introduced either by changing mechanical parameters of the instrument or by changing the electromagnetic index of refraction. Calculations based on light optical analogs of the fringe spacing, and their behavior with changes of instrumental parameters show good agreement with observations. The production of a fringe system by such an instrument suggests that the analogy between the physical optics of photons and of electrons is valid over a wider range of experiments than has been generally assumed. Some further implications of these observations with regard to the nature of the electron will be briefly discussed.

* This and the preceeding two abstracts are reports on work carried out as part of a cooperative program in basic instrumentation sponsored jointly by the U. S. Atomic Energy Commission, and the U. S. Office of Naval Research.

C11. Electron Distributions for Opacity Calculations. MALCOLM K. BRACHMAN AND ROLAND E. MEYEROTT, *Argonne National Laboratory.*—The Wigner-Seitz ion-sphere approximation has been employed for the determination of opacities.[1] We consider a model for the calculation which is based upon a procedure for joining a generalized Fermi-Thomas[2] free-electron density to a bound-electron density found by first-order perturbation theory. The scheme is similar to one based upon a detailed statistical treatment,[3] but the present considerations are more physical. The fact that opacity calculations seldom demand detailed information concerning electrons of ionization energy less than kT is exploited. The density is found as a function of the nuclear charge, the temperature, and a parameter α which specifies the bound-electron distribution. The equations involve the incomplete Fermi-Dirac function,

$$I_{\frac{1}{2}}(n, x) = \int_x^\infty \frac{y^{\frac{1}{2}}dy}{e^{y-n}+1},$$

which has been computed. Methods of integrating the equations are discussed.

[1] Morse, Astrophys. J. **92**, 27 (1940).
[2] Feynman, Metropolis, and Teller, Phys. Rev. **75**, 1561 (1949).
[3] G. Keller and R. E. Meyerott, Argonne National Laboratory Reports ANL-4771 and ANL-4856.

C12. Multichannel Pulse-Height Analyzer Using a Storage Tube.* J. A. CUNNINGHAM, *National Bureau of Standards.*—A simple and reliable electronic pulse-height analyzer permitting the use of many channels has been developed for pulsed accelerator applications. The voltage pulses to be analyzed are introduced to the vertical plates of a selected 3 JPI CRO tube, on whose outer face a wire screen has been mounted. During the accelerator off-time, a sawtooth sweep voltage is applied to the same deflection plates. The output pulses of the storage tube are then analyzed during the sweep. The time differences between the sweep start and the output pulses determine the heights of the original input pulses. A simple time gate-scaler device enables the use of a large number of channels. Tests on spectrum analyses have proven the following distinct advantages: (1) Voltage pulses whose peak values were maintained for a period as short as 0.05 microsecond have been analyzed. The minimum time response of the storage tube has not yet been checked. (2) Time differences and thus pulse-height measurements are independent within 0.1 percent of analyzer supply voltage changes of 15 percent. (3) With the available storage tubes it is easily practical to obtain 100 channels. A large ratio of the resolving power to the number of channels being used permits a small error due to boundary effects.

* Partially supported by the U. S. Office of Scientific Research of the Air Research and Development Command.

Invited Paper

C13. On Optimum Filter Design for Incompletely Specified Filter and Noise Processes. A. G. CARLTON, *Applied Physics Laboratory, Johns Hopkins University.* (30 min.)

THURSDAY MORNING AT 10:00

(H. A. BETHE presiding)

Shoreham, West Ballroom

Elastic Scattering of Charged Particles

CA1. Differential Cross Sections for the Elastic Scattering of 1.0- to 3.25-Mev Deuterons by He^3.* R. J. S. BROWN, K. F. FAMULARO, H. D. HOLMGREN,† AND D. M. VAN PATTER, *University of Minnesota.*—Differential cross sections have been measured at laboratory energies of 1.0, 1.5, 2.0, 2.5, 3.0, and 3.25 Mev at center-of-mass angles from 45° to 125° for deuterons elastically scattered from He^3. The small-volume scattering chamber and proportional counter have been described previously.[1] The cross sections for He^3 and its mirror nucleus H^3 are shown to be similar in magnitude and in variation with angle and energy.[1] Cross sections are higher for He^3 than for H^3 at low angles and energies, where the Coulomb forces prevail. In the angular range approximately from 50° to 90° (center of mass) the cross sections for He^3 are somewhat lower than those for H^3, and at higher angles the cross sections are roughly the same, except at the low energies. Allred *et al.*[2] found nearly identical cross sections for the two scatterings at 10 Mev.

* This work has been supported by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
† U. S. Atomic Energy Commission predoctoral fellow during most of this work.
[1] Stratton, Freier, Keepin, Rankin, and Stratton, Phys. Rev. **88**, 257 (1952).
[2] Allred, Armstrong, Hudson, Potter, Robinson, Rosen, and Stovall, Phys. Rev. **88**, 425 (1952).

CA2. Alpha-Alpha Scattering at 21.8 and 22.9 Mev (Proportional Counter).* G. R. BRIGGS,† S. SINGER, AND W. K. JENTSCHKE, *University of Illinois.*—Absolute cross sections for alpha-alpha scattering have been determined in the chamber previously used for *p-p* scattering.[1] In contrast to the *p-p* experiment, no correction for scattering in the foil windows of the double proportional counters was necessary because the foils were removed and the chamber gas was used as the counter filling. The helium pressure used was 21.7 cm Hg. In order to achieve sufficient gas multiplication and good pulse resolution, an addition of 0.04 cm CH_4 was necessary. The correction necessary to account for the CH_4 contribution to the scattering was determined by a separate experiment, and was never greater than 2.3 percent. For both alpha-particle energies, 21.8 and 22.9 Mev, the center of mass cross sections display maxima at laboratory angles of approximately 27° and 45° and minima near 20° and 40°, the fluctuations being greater at the higher energy. The pronounced energy dependence of the cross section is due to the influence of an excited level of Be^8.

* Assisted by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
† Now at the Digital Computer Laboratory, Massachusetts Institute of Technology.
[1] E. J. Zimmerman and P. G. Kruger, Phys. Rev. **83**, 218 (1951).

CA3. Alpha-Alpha Scattering at 21.6, 22.4, and 22.8 Mev (Nuclear Plate).* R. O. KERMAN, *Kalamazoo College,*† AND R. NILSON AND W. K. JENTSCHKE, *University of Illinois.*—Using a modification of the scattering chamber described previously by Rodgers *et al.*,[1] absolute differential alpha-alpha scattering cross sections have been measured at 33 angles ranging from 12° to 52° in the laboratory system for energies of 22.4 and 22.8 Mev, and at 11 angles from 24° to 52° at an energy of 21.6 Mev. The helium pressure used was approximately 20 cm Hg. The statistical errors range from one to two percent. Consistent with the data reported in the previous abstract, maxima of the cross section curve occur near 27° and 45°, and minima at 20° and 40°.

* Assisted by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
† Assisted by a grant from the Research Corporation.
[1] Rodgers, Leiter, and Kruger, Phys. Rev. **78**, 656 (1950).

CA4. The Elastic Scattering of Protons by O^{16}.* F. J. EPPLING, J. R. CAMERON, R. H. DAVIS, AJAY S. DIVATIA, A. I. GALONSKY, E. GOLDBERG, AND R. W. HILL, *University of Wisconsin.*—The differential cross section for elastic scattering of protons by O^{16} was measured in a differentially pumped gas scattering chamber[1] using protons accelerated in the electrostatic generator. Bombarding energies ranged between 0.28 Mev and 4.6 Mev. Cross sections were measured at eight scattering angles from 86.8° to 167.2° (lab). The shape of the cross section curve at 167.2° compares favorably with that obtained by the Laubensteins[2] at 159° to 169°; however, our measurements give a cross section value of 0.094 ± 0.002 barn per steradian at 2.00 Mev and 167.2°. A comparison between the results obtained at 86.8° (90.4°c.m.) and those predicted by the Laubensteins[3] shows that the 2.66-Mev resonance is $J=1/2^-$. The results at 3.47 Mev are not inconsistent with the assignment $J=7/2^-$. A preliminary extraction of the S, P, and $D_{5/2}$ phase shifts at low energies using graphical methods shows that a large S and a relatively large D phase shift are required to fit the data. Further analysis is in progress.

* Work supported by the Wisconsin Alumni Research Foundation and the U. S. Atomic Energy Commission.
[1] Jackson, Galonsky, Eppling, Hill, Goldberg, and Cameron, Phys. Rev. **89**, 365 (1953).
[2] Laubenstein, Laubenstein, Koester, and Mobley, Phys. Rev. **84**, 12 (1951).
[3] R. A. Laubenstein and M. J. W. Laubenstein, Phys. Rev. **84**, 18 (1951).

CA5. Elastic Scattering of Protons by Neon.* W. HAEBERLI, A. GALONSKY,† E. GOLDBERG,‡ AND R. DOUGLAS, *University of Wisconsin.*—Energy levels in Na^{21} have been observed by measuring the differential cross section of 0.2- to 4.4-Mev protons elastically scattered from neon at six angles from 90° to 167.5° c.m. Ordinary neon (91 percent Ne^{20}, 9 percent Ne^{22}) was differentially pumped through a gas scattering chamber and recirculated through a magnesium purifier. Inelastically scattered protons from the 1.277-Mev level in Ne^{22} and the 1.64-Mev level in Ne^{20} were stopped by placing absorbers in front of the proportional counters. These measurements, covering the range of excitation energy in Na^{21} from 2.64 to 6.61 Mev indicate levels at 4.20, 4.31, 4.48, 5.04, 5.50, 5.83,

5.58, and 6.48 Mev. By observing the inelastic scattering cross section as well (see following abstract) a few weak resonances could be attributed to Ne^{22}, indicating levels in Na^{23} at 11.14, 11.36, 11.53, 11.56, and 11.87 Mev. By using enriched Ne^{20} isotope we hope to show that other small anomalies in the cross section also are due to Ne^{22}. A phase shift analysis to classify the Na^{21} levels is in progress.

* Work supported by the Wisconsin Alumni Research Foundation and the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.
‡ U. S. Atomic Energy Commission Predoctoral Fellow.

CA6. Inelastic Scattering of Protons by Neon.* A. Galonsky,† W. Haeberli, E. Goldberg,‡ and R. Douglas, *University of Wisconsin.*§—The $Ne^{20,22}(p, p_1)$ differential cross sections were measured from 2.4 to 3.6 Mev. The above apparatus was used with absorbers chosen to maximize the separation in pulse height of the three proton groups: elastic ($Ne^{20}+Ne^{22}$), inelastic Ne^{20}, inelastic Ne^{22}. For each Ne^{20} elastic resonance an inelastic resonance appeared. The energies and cross sections at 168° are 2.72 Mev (0.13 barn), 3.21 (0.006), 3.56 (0.013), 3.58 (0.015). Elastic and inelastic resonances for Ne^{22} were observed at 2.43, 2.67, 2.83, 2.87, 3.19 Mev. At 3.42 Mev the elastic cross section (0.092 ± 0.002 barn) shows no anomaly while there is an inelastic resonance (0.014 barn, 10-kev width) at this energy. To check the classification[1] of the 1.63-Mev level of Ne^{20} the inelastic cross section was measured over the 2.72-Mev resonance at 12 angles from 33° to 168° and over the 3.56- and 3.58-Mev resonances at 7 angles from 63° to 168°. Preliminary calculations show that the 2.72-Mev angular distribution is not isotropic.

* Work supported by the Wisconsin Alumni Research Foundation and the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.
‡ U. S. Atomic Energy Commission Predoctoral Fellow.
§ Assigned to this session by request.
[1] Huby and Newns, Phil. Mag. **42**, 1442 (1951), report $J=0, 1, 2$.

CA7. Resonances in $S^{32}(pp)S^{32}$. A. J. Ferguson and H. E. Gove, *Chalk River Laboratories.*—The elastic scattering of protons from sulfur has been studied using the Chalk River electrostatic generator. The yield curve at 150° shows two resonances in the energy range of 1.0 to 2.8 Mev at 1.90 and 2.31 Mev, respectively. The angular distribution has been measured from 50° to 150° at frequent energy intervals over each resonance. A gas target in the form of H_2S was used employing a scattering chamber similar to that described by Blair *et al.*[1] The angular distributions have been compared with theory[2] and allow an unambiguous assignment for spin and parity of 3/2- and 1/2- for the 1.90- and 2.31-Mev resonances. The ratio to Coulomb scattering becomes approximately unity below the 1.90-Mev and above the 2.31-Mev resonance. The lower resonance is less than 25 kev wide and the upper one about 60 kev.

[1] Blair, Freier, Lampi, Sleator, and Williams, Phys. Rev. **74**, 553 (1948).
[2] John M. Blatt and L. C. Biedenharn, Revs. Modern Phys. **24**, 258 (1952).

CA8. The Energy Dependence of the Differential Elastic Scattering Cross Section of Alpha-Particles in Helium.* F. E. Steigert and M. B. Sampson, *Indiana University.*—Helium gas at 0.1 atmosphere pressure was bombarded with alpha-particles of energies 20.95, 19.62, 18.30, 16.55, 14.86, and 12.88 Mev (all ±0.06 Mev). The reduced energies were obtained from the cyclotron by placing aluminum absorbers in the ion beam. A monoenergetic beam was then obtained using a 32° analyzing magnet. The recoils were observed on Kodak NTA emulsions spaced every 7½° in a multiple angle camera. A pronounced angular dependence was observed, both for the absolute cross section and for the ratio to Rutherford scattering. This effect was especially marked at the higher energies. Phase shift analyses will be presented.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

CA9. Alpha-Particle Scattering in Nitrogen. N. P. Heydenburg and G. M. Temmer,* *Department of Terrestrial Magnetism.*—We have observed the elastic scattering of alpha-particles by nitrogen at 124°, 137°, and 156° in the c.m. system as a function of energy between 1.5 and 3.4 Mev with the singly charged alpha-beam from our elestrostatic generator and the scattering chamber previously used for alpha-alpha scattering.[1] The curves of scattering yield *vs* energy at these angles deviate considerably from Rutherford scattering and show very striking resonance effects above 2.7 Mev, the latter being most pronounced at 156° and indicating the presence of at least two resonances at approximately 2.9 and 3.1 Mev. They correspond to levels in the compound nucleus F^{18} at about 6.7 and 6.8 Mev. No levels have previously been reported in this energy region. A more precise location of these levels must await the outcome of a theoretical analysis of our scattering data.

* National Bureau of Standards.
[1] G. M. Temmer and N. P. Heydenburg, Bull. Am. Phys. Soc. **28**, No. 1, 11 (1953), Cambridge meeting.

CA10. Elastic Scattering of 1.7-Mev Electrons.* D. J. Anthony, B. Waldman, and W. C. Miller, *University of Notre Dame.*—Electrons from the Notre Dame pressure electrostatic generator were scattered from thin foils of aluminum and gold. The elastically scattered electrons were focused by means of a 90° single order focusing magnetic spectrometer at the anthracene crystal of a scintillation detecting system. Relative cross section measurements were made at scattering angles ranging from 30° to 150° in 30° steps. At 90° the foils were placed in both the reflection position and the transmission position. Measurements at 30° and 60° were normalized to transmission data at 90° and results at 120° and 150° were normalized to the reflection data at 90°. The results for aluminum agree to within 5 percent with the Mott[1] formula (Born approximation). Comparison with the McKinley-Feshbach[2] approximation formula is somewhat better. In the case of gold, agreement with Mott theory as calculated by Bartlett and Watson[3] is found to be about 5 percent.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission
[1] N. F. Mott, Proc. Roy. Soc. (London) **A124**, 426 (1929).
[2] W. A. McKinley and H. Feshbach, Phys. Rev. **74**, 1759 (1948).
[3] J. H. Bartlett and R. E. Watson, Proc. Am. Acad. Arts Sci. **74**, 53 (1940).

CA11. Electron Scattering from Nuclei at High Energies.*† R. Hofstadter, H. R. Fechter, and J. A. McIntyre, *Stanford University.*—Elastic scattering of electrons from nuclei at energies of 100 Mev or higher may be expected to demonstrate the finite dimensions of atomic nuclei. To study such effects a double-focusing spectrometer magnet has been constructed similar to the one with a 16-inch radius built by Snyder *et al.*[1] This magnet bends electrons of 135 Mev (maximum) through 180°. The electron beam of the Stanford linear accelerator has been cleared of gamma-rays and deflected into a 20-inch diameter scattering chamber. Elastically scattered electrons emerge from a thin scattering foil, pass through a 0.006-inch aluminum window on the scattering chamber and through a 0.003-inch aluminum foil into the magnet vacuum chamber. Čerenkov counters are used to detect the scattered electrons. The counting rate has been measured at various angles as a function of magnetic field and shows a peak at the value of the field expected for elastically scattered electrons. Preliminary angular distributions have been observed at 120 Mev with a thin lead scattering foil.

* This project was initiated and aided at all stages by a grant from the Research Corporation.
† Assisted by the Joint Program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Snyder, Rubin, Fowler, and Lauritsen, Rev. Sci. Instr. **21**, 852 (1950).

THURSDAY MORNING AT 10:00

Wardman Park, Continental Room

(E. R. GAERTTNER presiding)

Neutron Physics, I.

D1. Total Cross Sections for 400-Mev Neutrons.* V. ALEXANDER NEDZEL, *University of Chicago.*—Total cross sections of a number of elements have been obtained from good geometry transmission measurements in the neutron beam of the University of Chicago synchrocyclotron. A novel threshold detector is used to define a narrower energy spread of the effective neutron beam than is available directly form the cyclotron. The cross sections observed are as follows:

Hydrogen	—33.6±1 mb	Iron	—1.07±0.01 barn
Beryllium	—232 ±4	Copper	—1.19±0.01
Carbon	—298 ±3	Cadmium	—1.85±0.02
Oxygen	—379 ±5	Lead	—2.89±0.03
Aluminum	—588 ±6	Thorium	—3.23±0.05
Sulfur	—681 ±7	Uranium	—3.26±0.05
Chlorine	—743 ±7		

The hydrogen cross section was determined by measuring the attenuations of the neutron beam by samples of graphite, benzene, and cyclohexane. The errors shown are statistical errors of counting and the values must be regarded as tentative pending a more complete study of possible systematic errors in the experiment.

* Assisted by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.

D2. Time-of-Flight Instrumentation for 100-Mev Neutrons. W. I. LINLOR AND B. RAGENT, *University of California, Berkeley.*—Time-of-flight instrumentation has been developed which measures energies of neutrons from 30 Mev to 130 Mev with a resolution of ±1 Mev at 100 Mev, using a flight distance of 150 meters. The source is the stripped-deuteron beam of the 184-inch synchrocyclotron. Using an insulated beryllium probe, thick enough to stop 180-Mev deuterons, one manipulates the cyclotron controls to deflect a single pulse of deuterons on to the probe. The collection of charge and production of stripped neutrons occur simultaneously, resulting in a pulse of neutrons 10^{-8} second wide starting at a known place. A scintillation detector is in the beam. A given pulse from the probe and the corresponding pulse from the scintillator, resulting from the detection of a neutron by proton recoil, are displayed, after fast amplification, on the sweep of an oscilloscope. A camera records the sweeps. By observing a sufficient number of sweeps one obtains the energy spectrum of the neutrons in the beam, inasmuch as each pulse of neutrons contains a complete stripping spectrum. Energy calibration was accomplished by detection of gamma-rays from the probe.

D3. Total Neutron Cross Section of Lead from 30 to 150 Mev. B. RAGENT AND W. I. LINLOR, *University of California, Berkeley.*—The total neutron cross section for lead has been measured as a function of energy using the time of flight instrumentation developed for the 184-inch cyclotron. The measurement was done in a good geometry absorption experiment using a neutron flight path of 44 meters. The measurement shows a dip to 4.22±0.07 barns at about 55 Mev, followed by a rise to a peak of 4.87±0.06 barns at about 85 Mev, in good agreement with results previously reported.[1,2]

[1] A. E. Taylor and E. Wood, Phys. Rev. **87**, 907 (1952).
[2] A. E. Taylor and E. Wood, Phil. Mag. **44**, 95 (1953).

D4. A Time of Flight Method for Measuring Neutron Energies in the Mev Range.* B. JENNINGS AND G. L. GRIFFITH, *Westinghouse Research Laboratories.*—A simple beam chopping system applied to the output of a Van de Graaff generator produces deuteron pulses of 3 milli-microseconds length at a rate of 10^7 pulses/sec. The maximum current during the pulse is about 10 μA and the average current is 0.2 μA. These pulses of 1.6-Mev deuterons produce 4.4-Mev neutrons in a thin (200 kv) deuterium gas target. The arrival time of these neutrons at a terphenyl or stilbene counter one meter distant is displayed on a wide band oscilloscope using a sine-wave sweep synchronized with the beam pulsing mechanism. Gamma-rays produced at the target by the arrival of the deuteron pulse establish a zero time marker. The time of flight of a 4.4-Mev neutron, 34 m μsec, can be easily measured as can the 2.7-Mev neutrons from the same process at 90°. 500-kv neutrons from the Li(pn) process have been observed with a stilbene counter but their pulse height is low compared to background gamma-ray pulses. The problems of energy resolution, neutron intensity, and background, in the application of this method to the measurement of inelastic neutron cross sections will be discussed.

* Assisted by the joint program of U. S. Office of Naval Research and U. S. Atomic Energy Commission.

D5. Total Cross Sections of Nd, Er, and Hf for Fast Neutrons.* A. OKAZAKI, R. B. WALTON, AND J. D. CLEMENT, *University of Wisconsin.*—The total cross sections of Nd, Er, and Hf have been measured as a function of neutron energy from 50 kev to 3 Mev. Transmission experiments were performed using cylindrical samples of the elements. The solid angles subtended by the sample at the source and the detector were less than 0.016 steradian. The neutrons were produced by bombarding 120-kev thick Li and Zr-H[3] targets with protons from an electrostatic generator. These data give further evidence of regular variations in cross sections as a function of neutron energy and atomic weight.[1] The measured cross sections are in good agreement with those calculated by Feshbach, Porter, and Weisskopf,[2] on the assumption that the incident neutron moves freely within the nucleus in a potential hole, and that there is a probability different from one, for the formation of a compound nucleus during one traversal.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] H. H. Barschall, Phys. Rev. **86**, 431 (1952).
[2] Feshbach, Porter, and Weisskopf, Phys. Rev. **87**, 188 (1952).

D6. Total Neutron Cross Section of Liquid Argon.* JANET B. GUERNSEY AND CLARK GOODMAN, *M.I.T.*—Measurements of $\sigma_t(A)$ apparently[1] have not been made above 800 ev. Using liquid argon (99.6 percent A^{40}, density 1.41 g/cm^3) in the same special Dewar flask used for the determination[2] of $\sigma_t(N)$, we have measured $\sigma_t(A)$ from 0.4 to 1.1 Mev with a resolution of about 2 kev. Corrections for the glass container (about 9 percent) were determined from spot measurements on the empty flask. $Li^7(p, n)$ neutrons were used. The threshold of this reaction (E_p=1.882 Mev) provided the major energy calibration for the proton resonance magnet control. Repeat measurements of the No. 1 resonance in $\sigma_t(N)$ at E_n=430 kev are in excellent agreement with the previous data.[2] The nonresonant cross section averages about 0.7 barn. Resonant peaks of about 3.5 barns occur at 580, 600, and 740 kev. Smaller resonances occur, many of which are unresolved. The

level spacing observed decreases markedly with increase in neutron energy.

* Work jointly supported by U. S. of Naval Research and U. S. Navy Bureau of Ships.
[1] AECU-2040 Neutron Cross Sections (1952).
[2] Hinchey, Stelson, and Preston, Phys. Rev. **86**, 483 (1952).

D7. The Total Neutron-Proton Cross Section at 1 Mev.* R. E. FIELDS, R. K. ADAIR, R. L. BECKER,† AND S. E. DARDEN, *University of Wisconsin*.—The total cross section of hydrogen for 1-Mev neutrons has been determined by measuring the transmission of samples of 2-2-4 trimethylpentane and graphite. The neutrons were produced by bombarding thin targets of lithium oxide with protons from the electrostatic generator. Proton energy was measured with an electrostatic analyzer. A narrow neutron scattering resonance in sulfur was used to investigate the thickness and uniformity of the target. A one-inch helium recoil counter filled to a pressure of 350 pounds per square inch and placed 20 in. from the neutron source at 0° relative to the proton beam served as neutron detector. The discriminator was biased to reject pulses from neutrons of less than 550-kev energy, thus reducing the background to less than one percent and eliminating effects from the low energy group of neutrons from the $Li^7(pn)Be^7$ reaction. Preliminary calculation of the result of this measurement together with values of a_T, a_S, and r_T given by Burgy, Ringo, and Hughes[1] yields a singlet effective range in agreement with the proton-proton effective range.

* Work supported by the Wisconsin Alumni Research Foundation and the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.
[1] Burgy, Ringo, and Hughes, Phys. Rev. **84**, 1160 (1951).

D8. Inelastic Scattering of $D-D$ Neutrons.* R. E. GARRETT, F. L. HEREFORD, AND B. W. SLOOPE, *University of Virginia*.—The inelastic scattering of $D-D$ neutrons by various elements has been studied through observation of the gamma-radiation emitted by the de-exciting residual nuclei. Gamma-rays were detected in a 1-in. diameter by 1-in. thick NaI(Tl) scintillation crystal in coincidence with detection of scattered neutrons in a 1-in. cube of stilbene. Differential analysis of the NaI pulse height spectrum was performed for all such coincident events, yielding the energy spectrum of the gamma-radiation associated with scattered neutrons. Coincidence rates were normalized relative to a BF^3 proportional counter which detected neutron intensity in the vicinity of the target. The gamma-neutron coincidence technique eliminated background gamma-radiation. Four inches of paraffin shielded the stilbene crystal from both the deuterium target and NaI crystal. The following levels (given in Mev) have been observed in the indicated target nuclei: Mg: 1.40; Al: 0.84, 1.02, 2.2; Fe: 0.82, 1.45, 2.2; Cu: 1.1, 1.52, 2.14. Most of the Mg, Al, and Fe levels are in agreement with previously reported data obtained by similar methods.[1]

* Supported by U. S. Navy Contract.
[1] Robert V. Day, Phys. Rev. **89**, 908 (1953).

D9. Angular Distributions of Elastically Scattered 1-Mev Neutrons.* M. WALT† AND H. H. BARSCHALL, *University of Wisconsin*.—The differential cross sections of Fe, Ni, Cu, Zn, Ag, Cd, In, Sn, Hf, Pb, and Bi for the elastic scattering of 1-Mev neutrons have been measured every 15° from 30° to 150° with an angular resolution of 15°. Neutrons with an energy spread of 120 kev were produced by the $Li(pn)$ reaction and were detected by a recoil counter which was biased to reject neutrons of energy less than about 800 kev. The angular distributions appear to have varying characteristic shapes for elements in different parts of the periodic table while neighboring elements show similar distributions. All the elements investigated except Pb and Bi have maxima in both the forward and backward directions. Pb and Bi show peaks at 0° and at about 110°, and minima at 70° and 180°. By integrating the measured differential cross sections over all angles, preliminary values of the total elastic scattering cross section have been obtained. These values will have to be corrected for multiple scattering. The difference between the elastic cross section and the total cross section gives the inelastic collision cross section.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
† U. S. Atomic Energy Commission Predoctoral Fellow.

D10. Angular Distribution of Neutrons Scattered from Nitrogen. J. L. FOWLER, C. H. JOHNSON, AND J. R. RISSER,* *Oak Ridge National Laboratory*.—The angular distribution of elastically scattered neutrons was found from the pulse-height analysis of nitrogen recoils in a counter gas. Monoenergetic neutrons were produced by bombarding a tritium gas target with analyzed protons from the Oak Ridge National Laboratory 5.5-Mev electrostatic generator. The neutron energy scale was established by using the nitrogen recoil counter with low bias setting as a detector to locate the resonance peaks which have been observed in the total neutron cross section of nitrogen. Experimental widths of the observed peaks indicated the full width at half-maximum of the neutron energy spectrum was approximately 20 kev. The counter and detecting system resolved the 630 kev proton peak from the $N^{14}(n, p)C^{14}$ reaction produced by thermal neutrons with full width at half-maximum of about 6 percent. The angular distribution of neutrons scattered from nitrogen was found to change markedly as one increased the neutron energy across a resonance. For the 1.40-Mev, 1.60-Mev, and 2.22-Mev resonances there is an increased forward scattering of the neutrons. For the 1.35-Mev and 1.78-Mev resonances there is a peak in the angular distribution corresponding to backward scattering of the neutrons.

* Research Participant, The Rice Institute.

D11. Scattering of 14–18-Mev Neutrons in the Light Elements.* C. F. COOK AND T. W. BONNER, *Rice Institute*.—Scattering of monoenergetic neutrons, whose energy could be changed from 14 to 18 Mev, has been observed in H^1, H^2, Li^7, Be^9, B^{10}, B^{11}, C^{12}, and O^{16}. In general the cross section for scattering decreases slowly with energy. Over this range of energies the total cross sections for scattering are in the respective order $Be^9 > B^{10} > B^{11} > C^{12}$. Thus, Be^9 has a greater cross section than C^{12} at all energies. Other data do not indicate a larger radius for Be^9 than C^{12} so this decrease in the cross section as the number of nuclear particles is increased probably is due to the saturation effects as further particles are added to the nucleus.

* Supported by the U. S. Atomic Energy Commission.

D12. Gamma-Rays from 14-Mev Neutron Bombardment of C, O, Al, Fe, and Pb.* M. E. BATTAT, *Los Alamos Scientific Laboratory*.—The gamma-radiation from inelastic collisions of 14-Mev neutrons with various elements has been studied by Faust *et al.*,[1] Thompson,[2] and Waldman and Battat.[3] The present investigation utilizes a coincidence counter telescope, consisting of three thin-walled Al proportional counters arranged in a line, to detect the gamma-rays. Al was used as the converter and absorber material. The counter telescope was calibrated with gamma-ray sources of known energy and intensity, and the absorption curves were analyzed by the method of Bleuler and Zunti.[4] For the elements studied, the data indicate (1) a large cross section for the production of low energy gamma-radiation and (2) a high energy component, ranging in average energy from 3.5 Mev for Pb to 7 Mev for O. The cross section values obtained will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Faust, Scherrer, and Theus, Bull. Am. Phys. Soc. **28**, No. 1, 26 (1953).
[2] L. C. Thompson, Bull. Am. Phys. Soc. **27**, No. 5, 20 (1952).
[3] B. Waldman and M. E. Battat, unpublished.
[4] E. Bleuler and W. Zunti, Helv. Phys. Acta **19**, 376 (1946).

D13. Measurements of Neutron Capture γ-Rays with a Scintillation Spectrometer. T. H. BRAID, *Chalk River Laboratory.*[1]—Neutron capture γ-rays have been studied in the energy range 0.3 to 3 Mev. The experimental method and spectra from some elements have already been reported.[2] Further data will be presented. The spectra from capture in the elements listed below will be discussed. Many of the γ-rays may be assigned to transitions between known levels. The most prominent radiations are given in the table.

Magnesium	1.9, 2.8 Mev
Silicon	2.13, 2.65 Mev
Potassium	0.77, 1.19, 1.61, 2.03, 2.80 Mev
Calcium	1.93 Mev
Chromium	0.83 Mev

[1] Present address: Princeton University.
[2] T. H. Braid, Bull. Am. Phys. Soc. **28** No. 1, 26 (1953).

D14. Neutron Capture Gamma-Rays. W. A. REARDON, R. W. KRONE, AND R. STUMP, *University of Kansas.*—A two-crystal scintillation spectrometer[1] has been used to measure the energies of the gamma-rays resulting from the thermal neutron capture process. Measurements were made with a modification of the usual coincidence technique in that individual pulses were recorded on a moving film camera. The spectrometer was calibrated by Cs^{137} and Sb^{124} sources at low energy, and the $F(p, \gamma)$ reaction at high energy. The gamma-ray spectra of Cl, Co, and Cd were obtained in the energy range of 1 Mev to 5 Mev. The gamma-ray energies and their relative intensities will be presented.

[1] R. Hofstadter and J. A. McIntyre, Phys. Rev. **78**, 619 (1950).

THURSDAY MORNING AT 10:00

Shoreham, Main Ballroom

(H. D. SMYTH presiding)

Invited Papers

E1. Natural Variations in Abundance of Isotopes. L. T. ALDRICH, *Carnegie Institution of Washington.* (30 min.)

E2. Tritium in Nature. W. F. LIBBY, *University of Chicago.* (30 min.)

E3. Research Program of the Atomic Energy Commission. T. H. JOHNSON, *Atomic Energy Commission.* (45 min.)

THURSDAY MORNING AT 10:00

Wardman Park, Burgundy Room

(L. I. SCHIFF presiding)

Theoretical Physics (Nuclear Structure)

EA1. $1/W$ Terms in Allowed β-Spectra.* J. P. DAVIDSON AND D. C. PEASLEE, *Columbia University.*—A least squares analysis is made of the published spectra of He^6, P^{32}, Ca^{44} (β^+ and β^-), and N^{13} to determine the extent to which $1/W$ terms may be present. The presence of these terms would indicate a mixture of T and A or S and V terms in the β-decay interaction. The first three elements have $\Delta I = 1$ and give information only on the Gamow-Teller mixture (T, A); the N^{13} decay contains a relatively small Gamow-Teller part plus a Fermi part (S, V). It is found that the (T, A) mixture is of order 0.2 percent or less, the (S, V) mixture is of order 1 percent or less. These numbers are upper limits set by various errors; there is no evidence that the actual mixing ratios are different from zero. The mixing ratio is here defined as $gg'/(g^2+g'^2)$, where g and g' are the coupling constants of the two interactions concerned. To reduce the error limit on the (S, V) combination, additional measurements of odd $A\beta^+$ mirror transitions would be desirable.

* Work supported by the research program of the U. S. Atomic Energy Commission.

EA2. The Pauli Form of the Beta-Decay Matrix Elements. R. F. HERBST AND A. V. BUSHKOVITCH, *Saint Louis University.*—The method of canonical transformations of Foldy and Wouthuysen has been applied to calculate the nonrelativistic form of the nuclear matrix elements of the theory of beta-decay. The calculations are made using a single particle model and by applying the tables of Barker and Chraplyvy.[1] The results are in general agreement with the usual ones calculated by the method of successive approximations. The effects of cross terms between the beta-interactions and the nuclear potential are considered. While these effects are small, they

may be of importance in the pseudoscalar case. This discussion of the pseudoscalar case will be compared with that of Ahrens, Feenberg, and Primakoff.[2]

[1] W. Barker and Z. Chraplyvy, Phys. Rev. **89**, 446 (1953).
[2] Ahrens, Feenberg, and Primakoff, Phys. Rev. **87**, 663 (1952).

EA3. Evidence concerning Spin-Orbit Forces from β-Decay. I. TALMI AND E. P. WIGNER, *Princeton University.*—A. M. Feingold has shown (Princeton Dissertation 1952) that the effect of tensor forces on the low levels of Li^6, Li^7, and He^5 is similar to what one would expect from spin-orbit forces. Thus, for instance, at least half of the energy difference between the $P_{\frac{3}{2}}$ and $P_{\frac{1}{2}}$ levels of Li^7 can be explained by tensor forces. Feingold's wave functions are close to those of the supermultiplet theory and show essentially $L-S$ coupling. We found it difficult to explain the *ft* value of the β-transition from B^{12} to C^{12} on the basis of this picture. Although this *ft* value is about 7 times greater than would follow from the $j-j$ coupling model, it is too small for the present one. An allowed β-transition is possible only between levels the supermultiplets of which mix. The levels of B^{12} cannot be mixed with the lowest supermultiplet of C^{12} as this has only states with $T=0$. On the other hand, the supermultiplet of the ground state of B^{12} contains $T=0$ states only with $S=1$ which cannot be reached directly from the $S=0$ state of C^{12} by a tensor force. Hence, the β-transition in question appears as a second-order effect of the tensor forces and as such is too fast to conform with Feingold's picture. For spin-orbit forces the transition is a first-order effect.

EA4. The Reduction of the *E*1 Matrix Element in the Mixed *E*1+*M*2 Transition of Sr^{88}.* ROLF M. STEFFEN, *Purdue University.*—The directional correlation of the Sr^{88} gamma-gamma cascade was measured using liquid and solid sources of Y^{88}. The least square fit of the experimental data yielded the correlation function: $W(\theta)=1-0.0635\,P_2(\cos\theta)$. $A_2=-0.0635\pm0.0020$, $A_4=+0.0005\pm0.0015$. Special consideration was given to the correction for the finite angular resolution of the instrument. The directional correlation, together with the cross-over intensity (2 percent) and the internal conversion data of Metzger and Amacher[1] indicate a mixed $E1+M2$ transition (in phase) between states of angular momenta 3 and 2, followed by a pure electric quadrupole transition to the zero-spin ground state of Sr^{88}. The $M2$ to $E1$ intensity ratio of the first transition is 10^{-4}, whereas the intensity ratio calculated from the Weisskopf formula is 10^{-6}. This indicates a reduction of the $E1$ matrix element of the order of 10 in this particular case. The intensity ratio of the $M2$ transition and the $E3$ cross-over transition seems to be in very good agreement with the Weisskopf formula, whereas in many similar cases (e.g. $Cd^{114}Pt^{196}$) cross-over transitions to the zero-spin ground states are much less intense than expected.

* Supported in part by the U. S. Atomic Energy Commission.
[1] F. R. Metzger and H. C. Amacher Phys. Rev. **88**, 147 (1952).

EA5. $j-j$ Coupling for $A\lesssim50$.* R. W. KING, *Nuclear Development Associates,* AND D. C. PEASLEE, *Columbia University.*—Empirical evidence is surveyed regarding the validity of $j-j$ coupling in light nuclei, $A\lesssim50$. There is strong evidence against perfect $j-j$ coupling anywhere in this region, provided by failure of holes and particles to be equivalent, deviations in magnetic moments and superallowed β-decay matrix elements, and by specific nuclear reactions. There is rather less positive evidence that in spite of this failure, $j-j$ coupling is a useful first approximation for constructing a multiparticle shell model over much of the region $A\lesssim50$. There is faint evidence that the validity of the $j-j$ approximation improves through this region with increasing A. Experimental measurements needed to clarify these points will be discussed.

* Work supported by the research program of the U. S. Atomic Energy Commission.

EA6. The Ground State of Odd-Odd Nuclei. A. DE-SHALIT, *M.I.T.*—In an effort to derive the main features of Nordheim's rules for the spins of the ground states of odd-odd nuclei, an interaction of the form $[A+B\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2]\delta(\mathbf{r}_1-\mathbf{r}_2)$ was assumed between the two odd nucleons. Using well-known relations between the Clebsch-Gordan, Racah, and associated coefficients, the order of levels J in the jj coupling for two nucleons l_1j_1 and l_2j_2 moving in an arbitrary central field and interacting via the above perturbation is given by

$$E(j_1j_2J)=\frac{1}{2}\frac{(2j_1+1)(2j_2+1)}{(2J+1)}\,|(j_1\tfrac{1}{2}j_2-\tfrac{1}{2};\,j_1j_2JO)|^2$$
$$\times\left\{(A+B)\left[1+\frac{[(2j_1+1)+(-1)^{j_1+j_2+J}(2j_2+1)]^2}{4J(J+1)}\right]\right.$$
$$\left.-2B[1+(-1)^{j_1+j_2+J}]\right\}.$$

When the energy is plotted *vs* B/A two types of diagrams result according to whether $l_1+j_1+l_2+j_2$ is even or odd. In the first case $|j_1-j_2|$ is the ground state for any B/A, all the rest of the states being relatively highly excited (Nordheim's strong rule). In the second case, for $B/A>.2$, j_1+j_2 is the ground state, but j_1+j_2-2, j_1+j_2-4, etc., lie very close to it so that small configuration interaction could make one of these states the ground state (Nordheim's weak rule).

EA7. Collective Modes of Motion in Nuclei. F. VILLARS, *M.I.T.*—The limits of validity of the Bohr[1]-Hamiltonian, describing the lowest excited states of even-even nuclei in terms of collective modes, are investigated. Starting with a particle picture for the nucleus, the collective modes are introduced in terms of a "displacement field" $\delta_i(x)=\lambda_{ik}x_k(\lambda_{ik}=\lambda_{ki}$, $\mathrm{Tr}\,\lambda=0)$. The five variables λ take the roles of the surface amplitudes; they are introduced as dynamical variables along with five restrictions on the reduced positions $\xi_i^{(s)}=x_i^{(s)}-\delta_i(x^{(s)})$ of the nucleons (numbered by s),

$$m\sum_{s=1}^{N}\xi_i^{(s)}\xi_k^{(s)}=B(\xi)\delta_{ik},$$

expressing "spherical symmetry" of the distribution $\xi^{(s)}$. In an approximation $\psi=u(\lambda)\phi(\xi)$ for the wave function, the ξ-averaged Hamiltonian is exactly Bohr's, provided ϕ is a zero angular momentum state. The coupling of an additional nucleon follows the pattern outlined by Bohr as long as no additional core excitation occurs. The exclusion principle does not invalidate the picture for sufficiently heavy nuclei. With additional core excitation, considerable damping of the collective motion takes place. If we assume that tensor forces produce the $(L-S)$ coupling, additional excitation has to be assumed. More detailed features will be given.

[1] A. Bohr, Kgl. Danske Vidensk. **26**, No. 14 (1952).

EA8. Discontinuities in the Nuclear Mass Surface. ALEX E. S. GREEN AND DAVID F. EDWARDS, *University of Cincinnati.*—Proton and neutron binding energies are analyzed in such a way as to permit an approximate assessment of the effects associated with pairing and shell structure. We draw several interesting conclusions with respect to the accuracy of various theoretical expressions which have been proposed for the pairing effect. Our analysis of the data and considerations of an atomic model lead us to a simple approximate representation of a shell stabilizing correction to nuclear energies. This shell structure term accounts rather well for the observed departures from the general trends of beta-stability, nuclear masses, and nuclear Q values. Our shell correction suggests that much larger systematic variations in nuclear masses may be identified with shell structure effects than might previously have been suspected.

EA9. The Spin and Magnetic Moment of Li^8 Nucleus. G. E. TAUBER* AND TA-YOU WU, *National Research Council, Canada.*—Intermediate coupling theory is applied to Li^8 in

order to account for the observed spin of 1, and the magnetic moment $0.82\mu_N$. The nucleon-nucleon interaction is assumed to be of the form $mP+nQ$, where P denotes the Majorana and Q the Bartlett interaction. In order to get some indication of the effect of the form of the nuclear interaction on the result, calculations have been carried out for various types of potential and for various "ranges," exponential, Yukawa, and Gaussian. The constants m, n, and depth of the potential have been estimated from data for two free nucleons. The secular equations are solved by perturbation methods, the only unknown parameter being the spin-orbit interaction parameter ζ. The energy levels for the various types of interaction and "ranges" have been plotted against ζ, whose value is then determined from known ground and excited state of Li^6. The coupling is found to be much closer to $L\cdot S$ than to $j\cdot j$. The magnetic moment so calculated is about 0.87, in much better agreement with the experimental value than that obtained from extreme $j\cdot j$ coupling.

* Postdoctorate Fellow.

EA10. Magnetic Moment Deviations from the Schmidt Limits via Admixed States. A. B. VOLKOV, *University of Wisconsin.*—It has been noticed[1] that the relative deviations of the experimental magnetic moments from the Schmidt limits are nearly the same for pairs of odd-even nuclei of equal spin J, if the one has the same number (n) of odd protons as the other has neutrons. This result can be understood on the basis of two simple assumptions: that the angular momentum is distributed only among the n (odd) particles and that these particles satisfy a mirror condition between the two nuclei. Then the calculated relative deviations from the Schmidt lines are identical for any admixture of odd particle states. The experimental evidence may therefore be taken as an indication that, to a good approximation, the angular momentum is shared only among the n (odd) particles. If just this assumption is applied to any odd-even nucleus, one may obtain a simple expression for its magnetic moment as a function of the squared amplitudes of the Russell-Saunders terms of the admixed states. These results may be used in conjunction with the observed deviations to study the nature of the admixed states.

[1] A. L. Schawlow and C. H. Townes, Phys. Rev. **82**, 268 (1951).

EA11. Contributions to the Hyperfine Spectrum of He^3 Resulting from the Nuclear Structure. A. M. SESSLER* AND H. M. FOLEY, *Columbia University.*—The recent experimental determination[1] of the hfs splitting in the ^3S state of He^3 makes it important to compute the specific effects of the nuclear structure and the nucleon exchange currents. In first approximation it may be shown that the electrons near the nucleus move in orbits determined by the instantaneous positions of the two protons, as in the case of deuterium.[2] In this region a one electron treatment may be employed, and advantage is taken of the separability of the two center (H_2 ion) nonrelativistic problem. Relativistic corrections are then made. Calculation of the absolute value of the hfs splitting requires an accurate value of the electron charge density at the nucleus. Dr. P. J. Luke is engaged in this calculation.[3] The present work is expressed as a relative correction to the hfs as calculated for a point nucleus. The nuclear wave function of Pease and Feshbach[4] is used to determine the spatial distribution of the nucleons and the orbital hfs. The contribution of exchange currents to the hfs according to various models is being investigated.

* National Science Foundation Predoctoral Fellow.
[1] G. Weinreich and V. Hughes, Meeting of American Physical Society, Cambridge, Massachusetts (1953).
[2] A. Bohr, Phys. Rev. **73**, 1109 (1948); F. Low, Phys. Rev. **77**, 361 (1950).
[3] P. Luke (private communication).
[4] R. Pease and H. Freshbach, Phys. Rev. **88**, 945 (1952).

EA12. The Ground State of the Deuteron with Tensor Forces. I. M. H. KALOS AND J. M. BLATT, *University of Illinois.*—A program has been prepared for the Illinois high speed digital computer to solve the following problem: the potential acting in the ground state of the deuteron is written in the form $V=V_{c1}(r)+\lambda[V_{c2}(r)+V_t(r)S_{12}]$, where S_{12} is the conventional tensor operator and the three functions V are arbitrary (i.e., their numerical values at the netpoints used for integration of the differential equations are at the disposal of the programmer). An iteration method[1] is used which converges onto that value of λ which leads to the correct binding energy of the deuteron. The wave functions $u(r)$ (S state) and $w(r)$ (D state) are found during this iteration. The machine then computes and prints out the quadrupole moment, D state probability, and triplet state effective range implied by the potential, as well as a complete table of the wave functions u and w at each netpoint, normalized to $\int_0^\infty(u^2+w^2)\,dr=1$. The computation takes between 5 and 20 minutes, the printing takes another 5 minutes.

[1] Herman Feshbach and Julian Schwinger, Phys. Rev. **84**, 194 (1951).

EA13. The Ground State of the Deuteron with Tensor Forces. II. J. M. BLATT AND M. H. KALOS, *University of Illinois.*—The computing program described in the previous abstract has been used to investigate the dependence of the ground state parameters of the deuteron (quadrupole moment, D state probability) upon various features of the potential (range, depth, ratio of tensor depth to central force depth, ratio of the ranges, shapes). This has been done for conventional potential wells as well as for repulsive-core wells. The results will be discussed.

THURSDAY AFTERNOON AT 2:00

Shoreham, Terrace Room

(R. E. MARSHAK presiding)

Cosmic Rays: Stars, Curious Particles

F1. Cosmic-Ray Star Production Rates in Gases.* FIELDING BROWN† AND GEORGE T. REYNOLDS, *Princeton University.*—Extending earlier cloud-ion chamber studies of stars in neon, argon, and krypton,[1] the rates of star production at mountain altitude have been determined for stars of $\geqslant 1$ prong and for $\geqslant 3$ prongs. In the former case the star rate in Ne^{20} relative to that in Kr^{83} exceeds that expected from relative nuclear geometric areas by a factor of between 5 and 7. In the latter case the relative rate is 2.9 times the geometrical expectation. Rates in A^{40} are intermediate. Since large corrections have been necessary for those stars of 1 and 2 prongs missed due to instrumental bias; but little correction for stars $\geqslant 3$ prongs, the rates for $\geqslant 3$ prongs are considered more reliable. Such an effect is supported by earlier emulsion data at this altitude

A mechanism is proposed to explain the high star rate in light elements.

* Supported by the joint program of the U. S. Atomic Energy Commission and U. S. Office of Naval Research.
† Now at Sprague Electric Company, North Adams, Massachusetts.
[1] Brown, Rau, and Reynolds, Phys. Rev. **86**, 591 (1952).

F2. The Energy Distribution of Neutral Mesons Produced in Cosmic-Ray Stars. Y. B. KIM, *Princeton University.**—A multi-plate cloud chamber, the top plate of which is a NaI crystal and the successive plates are lead, has been operating at Echo Lake, Colorado, in order to study the energy distribution of neutral mesons emitted from cosmic-ray stars in the NaI crystal plate. Preliminary work in this line has been carried out by Salvini and Kim.[1] The essential idea is to have an unbiased selection of the stars. So far, we have accumulated about 200 neutral mesons, and we expect to obtain about 100 more before the termination of this experiment. A preliminary analysis on 150 neutral mesons indicates that the differential total energy distribution of neutral mesons is similar to that of the charged mesons,[2] i.e., $dN = dE/E^{\gamma}$, with $\gamma = 1.4$–1.7. Some inferences will be made on the angular distribution of neutral mesons from the measured angular distribution of the decay γ-rays. Also, some indication as to the natural frequency of unstable heavy mesons will be reported.

* Supported by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
[1] G. Salvini and Y. Kim, Phys. Rev. **88**, 40 (1952).
[2] Camerini, Fowler, Lock, and Muirhead, Phil. Mag. **41**, 413 (1950).

F3. Observations on Stars and Heavy Primaries Recorded in Emulsions during Flight of a Viking Rocket. HERMAN YAGODA, *National Institutes of Health.*—A series of emulsions were prepared at White Sands, New Mexico, and flown in NRL Viking No. 9 to a peak altitude of 135 miles. The preparations varying in thickness between 200 and 2300 microns were recovered in good condition several hours after impact and were developed underground together with a series of controls prepared from the same batch of Ilford G5 gel. The rocket plates exhibited a differential star count ($\geqslant 3$ prongs) of 6.0 cc^{-1} which if attributed to 400 sec of flight above 30 km indicates the production of 1300 ± 400 stars cc^{-1} d^{-1}. When compared with the control plates, the high altitude stars exhibit a greater frequency of associated minimum ionization tracks, and about 25 percent are initiated by charged particles. The latter include a number of events produced by relativistic particles of $Z \geqslant 2$ accompanied by large showers. An appreciable number of heavy primary tracks were recorded during flight (~ 0.8 cm^{-2}). The evaluation of their charge spectrum is in progress. Preliminary results on 73 tracks provide a ratio of 1.5 for CNO-nuclei to $Z \geqslant 10$. This suggests a greater preponderance of the heavier nuclei in the flux reaching the top of the atmosphere than deduced from stratosphere balloon exposures.

F4. Delayed Neutrons in Cosmic-Ray Stars. BYRON W. ST. CLAIR, *Syracuse University.*—An experiment was carried out at Echo Lake, Colorado, in which a NaI crystal was partly surrounded by a neutron-detecting liquid scintillator. Stars produced in the crystal were detected through a 5819 photomultiplier tube whose pulses operated a gating circuit. Pulses from a second photomultiplier tube looking into the liquid scintillator closed the gate whenever the scintillator recorded a neutron. The time interval between the two events was measured by counting with a fast scaling circuit the number of pulses received during this period from a 1 mc oscillator. The time distribution of about 11 000 events thus observed differs significantly from that obtained in control runs for randomly spaced background pulses. The preliminary analysis shows a frequency of about 0.25 delayed neutron per star, and a decay time of about 15 milliseconds.

F5. On the Energy Distribution of Neutron Stars.* R. W. WANIEK AND T. OHTSUKA, *Harvard University.*—The energy distribution of stars induced by high energy neutrons (90 Mev) was examined in the plates exposed by the method previously reported.[1] The actual range of the prongs was determined after careful correction for the shrinkage factor. Energies were determined from the observed ranges for protons and alpha-particles. Deuterons and tritons could not be discriminated from the protons. The energy distributions were plotted for different types of events and for different spatial angles. The general appearance of the spectrum resembles very much the one which would be expected from the evaporation theory. The maximum of the spectrum was practically the same for all star types and for all angles. For the protons the peak comes at about 2.5 Mev and for alpha-particles at about 5 Mev. About 50 percent of all the particles emitted were contained in these peaks. The angular distribution of these low energy particles shows a pronounced peak in the forward direction. The cross sections of star production for all events as well as for each type of event separately will also be presented.

* Assisted by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
[1] R. W. Waniek and T. Ohtsuka, Phys. Rev. **89**, 882 (1953).

F6. Cluster-Count Determination of Specific Ionization of Cloud-Chamber Tracks.* HANS O. COHN, L. R. ETTER, AND R. W. THOMPSON, *Indiana University.*—In an attempt to develop a method of determination of ionization which is more objective than the so-called "visual estimate of ionization" in the magnetic chamber, preliminary work is being done to investigate the possibility of using the number of clusters of drops per unit track length as an index of particle velocity. The method comprises counting the number of clusters equal to or greater than a predetermined size as indicated by an eyepiece reticule and comparison with the corresponding count in near minimum ionization tracks in preferably the same photograph. The p/μ value is then obtained from an empirical curve based on heavily ionizing pion tracks observed in penetrating showers during the course of the experiment.[1] For comparison tracks, electrons with momenta up to 75 Mev/c are used, this upper limit corresponding to muons which are heavily ionizing by a factor 2.3. The main uncertainty in the method is that of accepting or rejecting clusters near the minimum size. A mass spectrum will be shown.

* Assisted by the Office of Ordnance Research and by grant of the Frederick Gardner Cottrell Fund of the Research Corporation.
[1] Thompson, Cohn, and Flum, Phys. Rev. **83**, 175 (1951).

F7. Magnetic Cloud-Chamber Observations of *V*-Particles. I. Apparatus and Reduction of Data.* A. V. BUSKIRK, L. R. ETTER, C. J. KARZMARK, R. H. REDIKER, AND R. W. THOMPSON, *Indiana University.*—Further examples of V^0 decay have been observed in a sea level experiment,[1] now in progress, using the new magnetic chamber triggered by penetrating showers. Certain features of the temperature control system will be discussed, including the high capacity closed circulating system and the hollow pole design. Curvatures and angles are measured on the films with a comparator and corrections, generally small, are derived from stereoscopic reprojection through the original cameras. The distribution of no-field track curvatures indicates a maximum detectable momentum considerably in excess of 10^{10} ev/c. In a total of 3700 photographs obtained to date, there are 572 penetrating showers ($\geqslant 3$ particles). Among these, 25 V^0 decays are found, of which 12 have sufficiently long track lengths in the illuminated volume that the momentum determination is not likely to be in large error. Event R-118, in which the positive fragment, from ionization and momentum, is apparently less massive

than a proton, and the heavily ionizing negative fragment is identified to be a pion or muon, will be discussed in detail.

* Assisted by the Office of Ordnance Research and by grant of the Frederick Gardner Cottrell Fund of the Research Corporation.
[1] Proceedings of the Third Rochester Conference.

F8. Magnetic Cloud-Chamber Observations of *V*-Particles. II. Neutral *V*-Particles.* R. W. THOMPSON, A. V. BUSKIRK, L. R. ETTER, C. J. KARZMARK, AND R. H. REDIKER, *Indiana University.*—The average momentum of the events referred to in the previous abstract is rather high so that these events have been studied with the aid of the Q-curve plot.[1,2] A number of the events cluster on or near the curve $V_1^0 \rightarrow p+\pi+Q$, with a Q of 37 Mev, in agreement with the average value of 36 Mev previously reported by us,[3] and with the earlier value of 31 Mev.[4] The remaining events suggest the existence of a relatively large structure in the (α, p_T) plane, with approximate height $p_T = 200$ Mev/c, center near the origin, and width corresponding to a parent mass in the neighborhood of 1000 m_e. Six events can be fit with a single ellipse $V^0 \rightarrow (\pi \text{ or } \mu)+(\pi \text{ or } \mu)+Q$, where $Q = 210$ Mev and $M = 962\ m_e$ for the (π, π) decay. It would be premature to more than note the similarity to the τ-mass. However, two events do not fit very well and may be an indication of a 3-body decay, or may possibly constitute preliminary evidence for unresolved structure.

* Assisted by the Office of Ordnance Research and by grant of the Frederick Gardner Cottrell Fund of the Research Corporation.
[1] Proceedings of the Third Rochester Conference.
[2] It should be pointed out that the Q-curve plot can be used equally well in the analysis of charged V decays.
[3] Proceedings of the Second Rochester Conference.
[4] Thompson, Cohn, and Flum, Phys. Rev. **83**, 175 (1951).

F9. Momenta of V^0 Particles.* J. BALLAM, D. R. HARRIS, A. L. HODSON, R. RONALD RAU, GEO. T. REYNOLDS, S. B. TREIMAN, AND M. L. VIDALE, *Princeton University.*—Approximately 80 V^0 particles obtained with a magnetic field cloud chamber[1] at Echo Lake, Colorado are being analyzed for identification into V_1^0 and V_2^0 events. Where possible, the momentum of the V^0 particle is calculated from measurement of either the angles of decay products with the V^0, the momenta of the decay products or a combination of both. The results indicate good agreement with Fretter, May, and Nakada.[2]

* Supported by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
[1] Ballam, Harris, Hodsom, Rau, Reynolds, and Vidale, Bull. Am. Phys. Soc. **28**, No. 1, 40 (1953).
[2] Fretter, May, and Nakada, Phys. Rev. **89**, 168 (1953).

F10. A Speculation on *V*-Spin.* D. C. PEASLEE, *Columbia University.*—Qualitative agreement with some V^0 particle anomalies is obtained by assigning to these particles and to the nucleon (N) and π-meson an additional quantum number, "v-spin": $v=t=\frac{1}{2}$ for N; $v=0$, $t=1$ for π; $v=t=\frac{3}{2}$ for V_1^0; $v=t=1$ for V_2^0. Here t is isotopic spin. All strong nuclear forces are postulated to conserve v-spin absolutely and can lead to copious production of V particles in nuclear matter. This production is sometimes but by no means always in pairs. Interactions that violate v-spin are assumed to be very weak, accounting for the long lifetimes of isolated V^0. A serious problem of the V^0 is the absence of $V^\pm$ counterparts in comparable quantities. Some help is obtained by assuming that the charge number is (v_z+t_z), which removes a certain lack of symmetry among N, $\bar{N}$, π, and V^0. The situation is still not entirely satisfactory: the coupling of v and t must be assumed much stronger in V than in N to explain the lack of $V^\pm$. Also, an *ad hoc* rule must be postulated to prevent γ-decay of V^0.

* Work supported by the research program of the U. S. Atomic Energy Commission.

F11. Charged Zeta-Mesons. NATHAN SEEMAN, D. T. KING, AND MAURICE M. SHAPIRO, *Naval Research Laboratory.*—Two examples of the production and apparent decay of particles of mass $\sim 500\ m_e$ ($\zeta^\pm$ mesons) have been observed in G-5 emulsions exposed at $\sim$100 000 ft. Mass discrimination was enhanced in this study by selecting tracks of adequate length, and ionization satisfying $(0.5 < \beta < 0.8)$. Both zeta-tracks originate in interactions of moderate energy (probably <10 Bev) significantly similar to the K-meson events reported previously in that each star consists of three thin or grey tracks only. Each zeta-track suffers a deviation $\theta \sim 1°$ and an abrupt twofold increase in multiple scattering which is sustained throughout the rest of the track. There is no measurable change in velocity. Table I gives the basic data. τ_0 is the lifespan in the

TABLE I.

	Length	θ	β	$\bar{\alpha}°/(100\mu)^{\frac{1}{2}}$	M_0(in m_e)	$10^{11}\tau_0$ (sec)
Primary$_1$	3000μ		0.716	0.132	525 ± 100	1.1
Secondary$_1$	15 000μ	0.9°	0.716	0.260	263 ± 25	
Primary$_2$	7300μ		0.774	0.122	458 ± 100	2.0
Secondary$_2$	4000μ	0.7°	0.774	0.220	254 ± 35	

ζ rest frame. There is good evidence that the charged secondary is a pion. Assuming this two-body decay, the transverse momentum of the $\pi^\pm$ gives $Q \geq 40 \pm 10$ kev. The existence of a $\zeta^\pm$ is strongly suggested, if not firmly established, by these observations.

F12. The Decay of Heavy Mesons in Nuclear Emulsion. P. H. BARRETT, *Cornell University.*—Several events that have been identified as the decay of heavy mesons (K-particles) have been observed in 400μ G-5 nuclear emulsions that were surrounded by 5 cm of brass and exposed at 90 000 feet for 10 hours at 41° magnetic latitude. Results will be given of mass measurements on the K-particles and the mode or modes of decay will be discussed as they relate to the existence of kappa- and/or chi-mesons.

F13. Particle Selection Using a Crystal Telescope.* B. WOLFE,† J. DEWIRE, AND A. SILVERMAN, *Cornell University.*—An electronic technique for distinguishing nonrelativistic particles of different mass and/or charge has been developed. The method involves a measurement of E and dE/dx of the particle and an examination of the product EdE/dx. This product is proportional to $Z^2M^{-\frac{1}{2}}$. Previous techniques involved measuring dE/dx for particles of the same range. In this case dE/dx is proportional to $Z^{1.1}M^{-.45}$. Advantages of the new system are (1) greater separation of different particles for a given mass or charge ratio, and (2) since the product EdE/dx is only a slowly varying function of energy, a large range of energy can be detected simultaneously without substantial loss of resolution. A three-crystal telescope is used, the third crystal being an anticoincidence. dE/dx is measured in the first (thin) crystal and E in the second. These pulses are multiplied electronically to give an output pulse height proportional to $Z^2M^{-\frac{1}{2}}$. The energy spectrum of a particular particle is obtained by observing the pulse in the second crystal after being identified by the multiplied pulse. Experimental results will be discussed.

* Supported by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.

F14. The Zenith Angle Variation of Cosmic-Ray Meson Intensity.* ARTHUR BEISER, *New York University.*—The $\cos^2\zeta$ variation of cosmic-ray hard component intensity at low altitudes with zenith angle ζ is well known. If it is assumed that the hard component is composed largely of muons and that the pion momentum spectrum at production is $F(p)dp = p^{-2}dp$, the $\cos^2\zeta$ law follows directly. An exact relationship, valid for $F(p)dp = p^{-n}dp$, which takes into account ionization loss in traversing the atmosphere as well as $\mu - e$ decay, gives as a good approximation a $\cos^{n-1}\zeta$ dependence. Some consequences of this relationship will be discussed.

* Assisted by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.

THURSDAY AFTERNOON AT 2:00

NBS, East Building

(CYRIL S. SMITH presiding)

Ferroelectricity; Metals

FA1. The Case of Charged Density Distribution *Versus* Semipermanent Polarization as a Basis for Electret Behavior. W. F. G. SWANN, *Bartol Research Foundation.*—It is generally recognized that a distribution of volume and surface charges of total amount zero is equivalent, as regards field produced, to a suitably chosen distribution of polarization. A formal proof of this matter is given. The distribution of polarization lacks uniqueness to the extent of any contribution which, considered as a vector, is not derivable from a potential. It is shown that, if an electret were composed of ordinary charge distributions, its effects would diminish by fifty percent in a day or two on the basis of any reasonable assumption for the medium conductivity. Electret behavior must thus be based upon a semipermanent polarization decaying in a manner independent of conductivity. The effects observed can be regarded as arising from lag in the action of conductivity in providing for cancellation of the effects of polarization at each instant. The fact that the polarization, regarded as a submacroscopic distribution of charges, is itself not annihilated by the conductivity with a time constant appropriate thereto calls for explanation, and such is given.

FA2. Antiferroelectrics in an Applied Field. JACK R. TESSMAN, *Pennsylvania State College.*—Takagi[1] has shown, for a particular model of an antiferroelectric, that the electric susceptibility below the transition temperature will increase in an external electric field, E. He suggests this result may be valid for other antiferroelectric models. The same result can indeed be obtained with the phenomenological expansion of the Helmholtz free energy used by Kittel:[2] $A(P_a, P_b, T) = A_0 + (P_a^2+P_b^2)f + gP_aP_b + (P_a^4+P_b^4)h$. P_a and P_b are the polarizations of two identical sublattices and f, g, and h are functions of the temperature. The susceptibility, χ, may be expanded $\chi \equiv P' = P_0' + EP_0'' + E^2P_0''' \cdots$, where $P = P_a + P_b$, the prime indicates derivative with respect to E, and the subscript zero refers to the value at $E=0$. Below the transition temperature, $P_0''=0$ and P_0''' is positive. Therefore χ increases with an applied field and the increase is proportional to E^2. The increase of χ with E below the transition temperature has been observed[3] for lead zirconate and is in contrast to the behavior of ferroelectrics.

[1] Y. Takagi, Phys. Rev. **85**, 315 (1952).
[2] C. Kittel, Phys. Rev. **82**, 729 (1951).
[3] Shirane, Sawaguchi, and Takagi, Phys. Rev. **84**, 476 (1951).

FA3. Ferroelectricity in Rochelle Salt. JULIAN H. GIBBS, *General Electric Research Laboratory.*—The existence, in this crystal, of ferroelectricity between two "Curie temperatures" is attributed to a hydrogen-bridge polarizability which first rises and then falls with increasing temperature, exceeding the critical value for ferroelectricity in a narrow temperature range. It is shown, classically and quantum-mechanically, that a simple model for the potential wells associated with the protons in short hydrogen-bridges can give this behavior. The potentials are approximated by square wells with sloping floors. The slopes are applied to allow for the chemical asymmetry of these hydrogen-bridges. Half of the slopes are in the positive sense and half in the negative sense as indicated by the orientation of these hydrogen-bridges in the crystal. For a sufficiently large slope on each well-bottom, the polarizability of the second energy level of each proton exceeds that of the ground level of each. This allows the average polarizability of the Boltzmann-type assembly of hydrogen-bridges to rise at first as the temperature is raised from 0°K. The drop in polarizability with temperature at higher temperature is the result of the smallness of the polarizability of the upper levels.

FA4. Hall Effect in Pure Titanium, Vanadium, and Chromium.* SIMON FONER, *Carnegie Institute of Technology.*—The Hall effect has been measured by a dc method with fields up to 30 kilogauss for pure polycrystalline titanium, vanadium, and chromium at room temperature. The Hall coefficient for pure[1] titanium, $+0.95\times10^{-13}$ v-cm/amp-gauss, is smaller than the value obtained by Scovil.[2] However, the magnitude of the effect is very sensitive to impurities and, in fact, the Hall coefficient is negative for a commercial grade titanium. The coefficients for vanadium and chromium are $+8.13\times10^{-13}$ v-cm/amp-gauss and $+35.5\times10^{-13}$ v-cm/amp-gauss, respectively. The data for chromium are particularly interesting in view of its anomalously low electronic specific heat.[3] *3d* band conduction in these transition metals will be discussed in conjunction with available electronic specific heat data and recent Hall measurements for the neighboring ferromagnetic metals and alloys.[4]

* Supported by the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
[1] Sample and chemical analysis kindly furnished by Dr. D. S. Billington of the Oak Ridge National Laboratory.
[2] G. W. Scovil, J. Appl. Phys. **24**, 266 (1953).
[3] Estermann, Friedberg, and Goldman, Phys. Rev. **87**, 582 (1952).
[4] S. Foner and E. M. Pugh, Phys. Rev. (to be published).

FA5. Measurement of Thermal Diffusivity of Magnesium at Low Temperatures by Variable State Techniques.* S. WALDRON AND MELVIN A. HERLIN, *M.I.T.*—The measurement of thermal properties of metals at low temperatures by a pulsed and a sinusoidal heating of a rod of the metal has been investigated. The pulse measurements are shown to be seriously limited by the thermal resistance of the heater-to-sample interface. The sinusoidal measurements, however, are able to yield the thermal diffusivity (ratio of thermal conductivity to specific heat) and thus form a convenient method of obtaining this quantity. The method has been applied to magnesium, whose specific heat is known.[1] Two samples have been investigated, one of high purity, and one containing sufficient manganese impurity to show a pronounced electrical resistance minimum. The thermal conductivity derived from these results shows the normal linear variation with temperature at low temperatures for the pure sample, but a nonlinear variation in the direction expected from the electrical conductivity anomaly for the impure sample. Both samples show the characteristic maximum at higher temperatures.

* This work was supported in part by the Signal Corps, the Air Materiel Command, and the U. S. Office of Naval Research.
[1] Friedberg, Estermann, and Goldman, Phys. Rev. **85**, 375 (1952).

FA6. An Interpretation of "DC Etch" Phenomena. D. B. LANGMUIR, *Atomic Energy of Canada Limited.*—The rate of kinetic interchange across a line in the surface of a metal is $\sim D_s\rho$ g cm^{-1} sec^{-1} (D_s = surface diffusion coefficient, cm^2 sec^{-1}; ρ = density). If the diffusing particles are ions, an electric field E would produce, according to the Boltzmann relation, a net flow in one direction equal to $\sim D_s\rho(Ee\lambda/KT)$, where λ = interatomic spacing; e = electronic charge. If D_s varies with surface orientation, slight irregularities would tend either to build up

or even out according to the direction of net flow. The size of stable irregularities would be determined by a balance between the rate of build-up due to drift and of disappearance due to surface tension effects. The following experimental observations on tantalum support the above hypothesis: 1. dc heating produces "etching" on one side only of suitably oriented crystal grains in a 0.001-in. Ta strip. (Drift direction is reversed relative to crystallographic axes on opposite sides of the grain.) 2. 211 surfaces appear facing the positive end; 100, 310, and 110 planes develop facing the negative. 3. A thermal gradient produces effects similar to an electric field, with higher temperature equivalent to positive polarity. 4. Size and spacing of ridges developed by etching are consistent with reasonable values of D_s and surface energy.

* U. S. Atomic Energy Commission Liason Officer.

FA7. The Activation Energy for the Recovery of Reactor Irradiated Copper Crystals. J. K. REDMAN, R. R. COLTMAN, AND T. H. BLEWITT, *Oak Ridge National Laboratory.*—Five single crystals of high purity copper were irradiated in an Oak Ridge reactor to an integrated flux of 6×10^{18} neutrons per square centimeter. One of each of these crystals was isothermally annealed in a salt bath at each of the following temperatures: 305°C, 325°C, 345°C, 365°C, and 385°C. In no case was recrystallization observed despite the fact that the irradiation raised the initial shear stress for plastic flow from 0.2 kg/mm² to 3.5 kg/mm². The critical shear stress was determined as a function of annealing time at each of the above temperatures. The relaxation time varied from about 400 hours at 305°C to 11 minutes at 385°C. Using the data collected in this manner an activation energy of 2.2 electron volts was determined from the slope of the line relating the natural logarithms of the relaxation time to the reciprocal of the temperature. Although the isothermal recovery curves are indicative of a higher order, there is evidence that the recovery is that of a first-order reaction. The fact that the above-determined activation energy is apparently equal to that for self-diffusion is believed to be significant, and will be discussed.

FA8. The Effect of Strong Electrostatic Fields on the Resistance of Tungsten Wires. W. J. DESHOTELS AND A. H. WEBER, *Saint Louis University.*—The effect of a radial electrostatic field upon the resistance of tungsten in high vacua was reinvestigated employing lower pressures and better vacuum technique than in the original experiments.[1-3] Wires of 0.004-in. and 0.00045-in. diameter were subjected to negative and positive fields up to 9.0×10^6 and 1.4×10^6 volts/cm, respectively. The resistance abruptly decreased upon application of the electric field, increased slightly with time while the field was constant, and increased abruptly upon removal of the field. The abrupt increase was usually somewhat less than the abrupt decrease. The abrupt resistance changes satisfied the equation $\Delta R=\alpha E^4$, where ΔR=resistance change, E=applied field in volts/cm$\times10^6$, and $\alpha=0.46$. A large part of the small resistance change with constant field was due to an observed filament temperature increase resulting from bombardment by the electronic portion of the observed ion-, photo-, and field emission current. It was found that the photo and ion currents were much larger than the field emission currents. No observable electrostatic effect was found which could account for the abrupt resistance changes.

[1] A. G. Worthing, Phys. Rev. **17**, 418 (1921).
[2] G. B. Estabrook, Phys. Rev. **63**, 352 (1943).
[3] P. L. Vissat, Phys. Rev. **64**, 119 (1944).

FA9. The Stress-Strain Curves of Copper Single Crystal at 4.2°K. T. H. BLEWITT, R. R. COLTMAN, R. E. JAMISON, AND J. K. REDMAN, *Oak Ridge National Laboratory.*—Pairs of single crystals were grown by the Bridgman technique from high purity copper and annealed in high vacuum at 1030°C for three hours. The crystals were grown in the shape of ⅛-in. tensile bars. One of each pair was deformed at 4.2°K and the other at a higher temperature. The stress-strain relationship shows a dependence of temperature which is consistent with the earlier conceptions[1] based on deformation at 78°K and at 300°K. The critical shear stress at 4.2°C shows little if any increase over that at 300°K and the stress-strain curve is linear so long as the deformation occurs by slip. The high and low temperature curves are coincident over the linear portion of the high temperature curve. After a stress of approximately 15 kg/mm² is reached, which is greater than that obtainable at 78°K, the crystal deforms by twinning. After considerable strain by twinning the crystal fractured by cleavage. This latter phenomenon has not been observed at 78°K or higher temperatures.

[1] Blewitt, Redman, and Sherrill, Bull. Am. Phys. Soc. **28**, No. 2, 38 (1953).

FA10. Small Angle Scattering of X-Rays from Cold Worked Crystals. D. L. DEXTER, *University of Rochester.*—The small angle scattering of x-rays or thermal neutrons ($\lambda\sim1$A) from cold-worked crystals is calculated on the basis of a model which takes into account the density variations around edge-type dislocations, which neglects the effects of screw-type components (since the density variations are small), which neglects end effects at the termination of an edge-type segment, and which neglects coherence in the scattering from the regions surrounding different dislocations. The angular variation in the density change around an edge-type dislocation results in a complete modification of the usual small angle scattering formulas. The highly characteristic scattering curve shows a parabolic increase from zero at zero scattering angle, a maximum, and finally a monotonic decrease with increasing scattering angle. Multiple scattering will be negligible even in thick samples. There is large anisotropy in the scattering from an ordered array of dislocation. Scattering from dislocations does not explain the measured[1] scattering from cold-worked Cu, but may be observable under suitable conditions.

[1] J. Blin and A. Guinier, Compt. rend. **233**, 1288 (1951).

FA11. An Anomaly in the Heat Content of a Metal in the Fatigued State. B. WELBER AND R. WEBELER, *National Advisory Committee for Aeronautics.*—Three copper specimens were fatigued almost to fracture. To determine their heat content calorimetric measurements carried up to 450°C were made in the same way used previously to determine the energy stored in cold work.[1] In the following, a sample once heated up to 450°C during a measurement is designated as annealed. It was found that 0.36 ± 0.05 more cal/g were required to bring a fatigued sample from 250°C to 350°C than an "annealed" one. Thus, it appears that, quite unexpectedly, the fatigued state is one of *lower* heat content than the "annealed" state, while the cold worked state is one of *higher* heat content than the annealed state. Moreover, in fairly severely cold worked copper about 0.3 cal/g is released between 150°C and 250°C,[1] a temperature range within which the fatigued sample neither releases nor absorbs energy in amounts exceeding the experimental error of 0.03 cal/g. This is of interest since fatigue is supposed to be caused by localized strain hardening.

[1] B. Welber, J. Appl. Phys. **23**, 876 (1952).

FA12. Work Hardening in Substitutional Alloys. J. S. KOEHLER, *University of Illinois.**—It is shown that the mechanical properties of single crystals of the face-centered cubic alloys can be understood by supposing that source hardening and impurity hardening are important whereas interaction hardening is not. Source hardening arises because the Frank Read generators which can act at low stresses lock after giving a finite amount of glide. The internal stresses

produced by impurities impede the motion of dislocations particularly at small strains. Interaction hardening arises because the motion of dislocations past one another becomes more difficult as the density of dislocations rises. Observations on slip bands and stress strain data imply that the production of a new slip band is accompanied by a reduction of the impurity stresses nearby. It is suggested that vacancies and interstitials produced during the slip process diffuse away from the original slip band and settle down so as to annul the internal impurity stresses. This implies that the "purification" range should be reduced at low temperatures. T. H. Blewitt[1] has found that the width of a cluster of slip bands in alpha-brass after a given strain decreases as one goes to low temperatures. This agrees with the above theoretical suggestion.

* Supported by the U. S. Office of Naval Research.
[1] T. H. Blewitt, Bull. Am. Phys. Soc. **28**, No. 2, 39 (1953).

FA13. Tensile Strength and Adhesion of Thin Films of Silver.* H. S. MORTON, JR., AND J. W. BEAMS, *University of Virginia.*—Studies of the tensile strengths and adhesion of thin metal films by subjecting them to high centrifugal fields have been continued.[1] The silver films were electrodeposited without "striking" on small cylindrical steel rotors and the rotational speeds required to throw them off were measured. The rotors were magnetically suspended and spun in a high vacuum. The tensile strength, in agreement with the previous results, showed an abrupt increase at a thickness of roughly 2×10^{-6} in. Also the adhesion starts increasing rapidly at a thickness of about 1.6×10^{-6} in. Prolonged annealing at a temperature of 300°C increased the adhesion. Rapid cooling and heating between limits of 90°C and −70°C greatly reduced the adhesion and facilitated tensile strength measurements with small film thicknesses. The adhesion, of course, depended upon the method of electrodeposition.

* Supported by Navy Bureau of Ordnance.
[1] Beams, Walker, and Morton, Phys. Rev. **87**, 524 (1952).

FA14. The Structure and Aging of Thin Metal Films. I.* ROBERT J. RAUDEBAUGH AND RICHARD B. BELSER, *Georgia Institute of Technology.*—Electron diffraction studies of thin metal films have shown that such films, whether deposited by vacuum evaporation, sputtering or electroplating, are composed generally of small crystallites of the metal. Because these films are deposited atom by atom, or little by little, on a normally foreign surface and intermingled with foreign atoms during their growth, they are subjected to a certain amount of disorder and strain not so predominant in a metal cooling in bulk from a molten condition. After deposition, with time alone or with a temperature increase and time, a rearrangement of the atoms of a thin metal film to a state of greater order usually occurs. This transition may be detected by measurement of changes in electric resistance, in optical properties, and in x-ray and electron diffraction patterns of the film. This susceptibility to change, designated as "aging," appears to be inherent in the nature of the growth of the film. This aging is accelerated by heating the film, and there appears to be a certain temperature unique to each metal and its thickness at which an optimum condition of the film is attained.

* Supported by the U. S. Army Signal Corps.

FA15. The Structure and Aging of Thin Metal Films. II.* RICHARD B. BELSER AND ROBERT J. RAUDEBAUGH, *Georgia Institute of Technology.*—Examination of thin films of silver, gold, copper, platinum, and other metals, deposited by evaporation and sputtering on glass substrates, has shown that these films undergo a change in structure with time, either at room temperature or at elevated temperatures. Electron micrographs of films 50–250 angstroms thick may or may not show an initially visible particle size. By heating these films a growth of particle size is produced. This growth is accompanied by better definition of the lines of x-ray and electron diffraction patterns and some evidence of orientation. The resistivities of these films and thicker films generally undergo a reduction concurrently with the structural change. If a film be heated to a temperature above one specific to the metal and its thickness, defined as the "preferred" aging temperature, aggregation of the film will commence and its resistivity usually increases. At a somewhat higher temperature complete aggregation usually occurs. For 1000 angstrom evaporated films "preferred" aging temperatures have been found as follows: Copper and silver, 175–225°C; gold, 250–300°C; platinum, nickel, aluminum, and iron, 400–500°C. These temperatures appear to be related to the recrystallization temperatures of respective metals. Sputtered films may require somewhat higher temperatures for proper aging.

* Supported by the U. S. Army Signal Corps.

FA16. Precipitation Effects in Copper-Iron Alloys. THOMAS S. HUTCHISON, *Royal Military College of Canada.*—Alloys of copper with up to 1.5 percent iron have been investigated by electrical, magnetic, and x-ray diffraction methods. The particular form in which the iron exists in the different alloys can be deduced from a coordinated study of the results from the three sets of investigations. With the particular heat treatment applied to all the alloys (long vacuum anneal at 850°C followed by furnace cooling) lattice parameter measurements show that the iron can be maintained in supersaturated solid solution up to 0.26 percent. A peak in the value of electrical resistance also occurs at this iron content. Beyond this point it is believed that the iron begins to form a coherent precipitate, until, at an iron content of 0.5 percent, incoherent precipitate in the α-phase begins to form. This is accompanied by a marked rise in magnetic susceptibility of the alloys, and at the same time the body-centered cubic lines of α-iron are observable in the x-ray diffraction pictures.

THURSDAY AFTERNOON AT 2:00

Wardman Park, Continental Room

(C. O. MUEHLHAUSE presiding)

Neutron Physics, II.

G1. Measurement of Resonant Neutron Scattering Cross Sections.* C. SHEER, J. MOORE, AND C. HEINDL, *Columbia University.*—The thick target method[1] for measuring the ratio of scattering to total cross section has been used to study a number of neutron resonances. Methods have been worked out for analyzing experimental scattering data for level parameters in cases where the levels are resolved. Completely resolved spectra are obtained for capture levels below about 10 ev and nearly resolved curves for levels lying between 10 and about 30 ev. When the experimental curve is resolved,

the value of Γ_N/Γ for the resonance is obtained directly. The level strength ($\sigma_0\Gamma^2$) is then obtained from an area measurement under the scattering curve. Nuclear radii are determined by fitting the data in the neighborhood of the scattering minimum. For cases where the experimental curve is not quite resolved, Γ_N/Γ is obtained by curve fitting, taking the resolution width of the apparatus into consideration. The 5.13 ev resonance in Ag 109, the 16.6 ev resonance in Ag 107, and the 2.36 ev resonance in Te^{122} have been analyzed. These results together with preliminary results for the cobalt 126 ev, manganese 345 ev levels will be presented.

* Supported by the U. S. Atomic Energy Commission.
[1] Jay Tittman and Charles Sheer, Phys. Rev. **83**, 746 (1951).

G2. Neutron Resonances in Silver. W. Y. KATO, MARILYN J. STAFNE, J. S. LEVIN, AND D. J. HUGHES, *Brookhaven National Laboratory.**—The total cross section of normal silver has been measured in the energy region 5–500 ev with the Brookhaven fast chopper. The present time resolution is limited to ½ percent by the flight path in the counter at low energy, and to 3 μsec by the counter collection time at high energy. At this resolution it is felt that practically all resonances have been resolved up to 100 ev; the observed level spacing below 100 ev agrees with that obtained from 1 Mev capture cross sections.[1] For most of the nine resonances found below 100 ev, only the quantity $\sigma_0\Gamma^2$ can be measured because all samples used are thick relative to the actual resonance peak σ_0. The values of $\sigma_0\Gamma^2$ are corrected for Doppler broadening, which is about five times the true width Γ at 100 ev. If Γ_γ is assumed to be 0.1 ev, the Γ_n's for eight of the levels lie between 1.3 and 5.6 mv (converted to the value at 1 ev to remove the velocity factor), in agreement with the value expected, on the usual statistical model, from the observed level spacing. A level at 46 ev, however, has a Γ_n of only 0.2 mv.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] Garth, Hughes, and Levine, Phys. Rev. **87**, 222 (1952).

G3. Low Energy Neutron Resonance Scattering.* H. L. FOOTE, JR.,† *Brookhaven National Laboratory.*—A new crystal spectrometer has been developed at Brookhaven National Laboratory for the observation of low energy neutron resonance scattering. A beryllium single crystal is used as a monochromator and a lithium iodide tin activated scintillation crystal as a detector. The salient features of the instrument will be described. Preliminary results on the 1.458 ev resonance of indium[1,2] and the 2.37 ev resonance of tellurium[3] have been observed, and a scattering peak has been obtained in each case at approximately the resonant energy. The analysis of the tellurium resonance will be discussed.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
† Doctorial candidate from the University of Utah.
[1] B. N. Brockhouse, Can. J. Phys. (to be published).
[2] L. B. Borst, Bull. Am. Phys. Soc. **28**, No. 1, 25 (1953), Phys. Rev. (to be published).
[3] C. Heindl and I. W. Ruderman, Phys. Rev. **83**, 660 (1951), and C. Heindl, private communication.

G4. Occurrence of Neutron Resonances in the Rare Earths.* V. L. SAILOR, H. H. LANDON, AND H. L. FOOTE, JR., *Brookhaven National Laboratory.*—A survey of the slow neutron cross sections of the rare earth elements[1] has been completed with the exception of Nd, Pm, and Tb. Measurements were made over the energy range from 0.1 to 30 ev with the Brookhaven National Laboratory crystal spectrometer. The rare earth elements in the vicinity of the closed neutron shell ($N=82$), i.e., La, Ce, and Pr apparently exhibit complete absence of resonances up to 30 ev. On the other hand, the elements from $Z=62$ to 71 are characterized by a copious abundance of resonances. A crude estimate of the average level density can be obtained from the spacing of the resonances. The level density varies between the limits, 8 ev to 40 ev for the average isotope of the elements $Z=62$ to 71, the spacing in the isotopes of odd mass being consistently smaller than those of even mass. A comparison will be made between the elements in the rare earth region and the elements in neighboring regions.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] This work was made possible by the generosity of Dr. F. H. Spedding, of the Ames Laboratory, U. S. Atomic Energy Commission, in making available exceptionally pure specimens of most of the rare earths.

G5. Doppler Effect on Neutron Resonance Levels.* E. MELKONIAN, W. W. HAVENS, JR., AND L. J. RAINWATER, *Columbia University.*—In applying the area method of analysis of neutron resonance transmission dips,[1] Doppler broadening has usually been neglected. With improvements in both the methods of analysis and in the data, it is now necessary to take the Doppler effect into account, and extensive calculations have been performed in a way which is generally applicable. The area above a transmission dip is given by

$$[A_E]_D=\Gamma/2\int_{-\infty}^{\infty}[1-e^{-n\sigma_0\psi(x,\,\Gamma/\Delta)}]dx,$$

where $\psi(x, \Gamma/\Delta)$ is the Breit-Wigner cross-section formula with the Doppler broadening applied, Δ=Doppler width, and $x=2(E-E_0)/\Gamma$. The quantity $[A_E]_D/A_E$ (where A_E is the corresponding area with $\Delta=0$) is the factor by which the Doppler effect increases the area above a transmission dip. This ratio has been calculated for a wide range of values of Γ/Δ and $n\sigma_0$. ($\Delta/\Gamma=0.3,\ 0.5,\ 2,\ 5,\ 50,\ \infty$; $0.1\leq n\sigma_0\leq 100$.) Plots of the calculations will be shown and application to the area method discussed.

* Supported by the U. S. Atomic Energy Commission.
[1] W. W. Havens, Jr., and L. J. Rainwater, Phys. Rev. **83**, 1123 (1951).

G6. Neutron Transmission Measurements of Cadmium, Gadolinium, and Mercury Using the Argonne Fast Chopper. R. RONALD PALMER* AND LOWELL M. BOLLINGER, *Argonne National Laboratory.*—Neutron transmission measurements of cadmium, gadolinium, and mercury and the separated isotopes of cadmium and mercury, with flight paths of 10, 20, and 40 meters, will be reported. Resolution, which improves with distance, is about 0.13 μsec/m (full width at half-maximum) at 40 meters. Gadmium shows resonance transmission dips at neutron energies of 18.0, 27.2, 66.6, 88.2, 122, 163, 234, 400, and 840 ev, with the 27.2- and 88.2-volt dips most prominent. The 27.2-volt dip is assigned to the Cd^{111} isotope; the 82.2-volt dip, tentatively to Cd^{110}. Transmission dips for gadolinium occur at 1.93, 2.58, 2.85, 6.26, 7.74, 11.6, 14.4, 16.6, 20.6, 22.2, 29.8, 33.2, 49, 81, 109, 355, and 740 ev, with the 2.58, 2.85, 20.6, and 22.2-volt dips most prominent. Mercury shows transmission dips at 23.1, 33.3, 42.8, 71, 91, 127, 175, 204, 311, 437, and 1230 ev, with the 23.1, 33.3, 175, and 311-volt dips most prominent. The 33.3 and 175-volt dips are assigned tentatively to Hg^{201}.

* On leave from Beloit College, Beloit, Wisconsin.

G7. The Absorption Cross Section of Gold and Boron for Thermal and Cold Neutrons. R. S. CARTER, H. PALEVSKY, AND V. W. MYERS,* *Brookhaven National Laboratory.*†—The absorption cross sections of gold and boron have been measured with the Brookhaven slow chopper over the wavelength region from 1.8 to 11A. These cross sections are important because they constitute comparison standards for much slow neutron work. For gold, beyond the Bragg cutoff (4.7A) the total cross section consists of capture and inelastic scattering only, the latter being very small (0.3 b). The cross section between 4.8 and 11A follows a 1/v law and the slope of the curve is 54.3 barns/A. If gold followed a 1/v law to thermal (2200 m/s), this slope would give an absorption cross section of 97.5±0.3 b. As the measured total cross section at thermal

is 104 b, either an unusually low scattering cross section or a slight departure from 1/v is indicated. The boron measurement was made with two samples of boron of normal isotopic content, B_2O_3 in glass prepared and analyzed by Corning for Columbia University, and the Argonne standard B_2O_3 dissolved in D_2O. The value obtained at 2200 m/s for normal boron is 753±3 barns. Enriched boron (96 percent B^{10}) is being measured as a check on the isotopic constitution of normal (source-California) boron.

* On leave from Pennsylvania State College.
† Work carried out under contract with the U. S. Atomic Energy Commission.

G8. Total Neutron Cross Sections of Heavy Water and Glass at Long Wavelengths. V. W. MYERS,* R. S. CARTER, AND H. PALEVSKY, *Brookhaven National Laboratory.*†—The cross sections of D_2O and boron-free glass at room temperature have been measured from 4 to 15A with the Brookhaven slow chopper. In the wavelength region covered, the capture cross sections of these materials is small compared to the scattering. The coherent scattering due to liquid structure is observed in both materials but essentially disappears at 10A. As the wavelength is increased beyond 10A, the measured cross sections rise monotonically and approach a 1/v law. From the work at Brookhaven on the inelastic scattering of neutrons in solids, it is known that the inelastic scattering approaches 1/v at long wavelengths; hence the residual scattering in D_2O and glass is interpreted to be inelastic scattering plus a constant contribution due to incoherent scattering. For D_2O the inelastic cross section at 10A is 15 barns per molecule and in glass at the same wavelength it is of the order of 5 barns per SiO_2 molecule.

* On leave from Pennsylvania State College.
† Work carried out under contract with U. S. Atomic Energy Commission.

G9. Coherent Cross Sections of Iron and Nickel. M. D. GOLDBERG AND J. A. HARVEY, *Brookhaven National Laboratory.**—Coherent scattering cross sections (σ_{coh}) can be obtained from free atom (σ_{fa}) and incoherent scattering ($\sigma_{in\ coh}$) cross sections. σ_{fa}'s of iron and nickel have been determined from total cross-section measurements using broad energy distributions of pile neutrons. This method is applicable when the total cross section is nearly constant with energy. Different energy distributions can be selected by proper combinations of B^{10} filters and differences, and the median energy for each distribution can be calculated. Two beams were used and the cross section measured both absolutely and relative to bismuth, which has a σ_{fa} of 9.28±0.02 b. A correction for capture was applied and other small corrections considered. The σ_{fa}'s of iron and nickel were determined as 11.39±0.04 b and 17.43±0.05 b, respectively. These agree with the indium resonance neutron measurements of Rayburn and Wollan.[1] The $\sigma_{in\ coh}$ for iron, calculated from the isotopic contributions and measured by a slow chopper, is 0.43±0.03 b, which, when subtracted from the bound atom cross section, yields a σ_{coh} of 11.37±0.05 b. A calculation of $\sigma_{in\ coh}$ of nickel yields 5.0±0.3 b; a more accurate chopper measurement is in progress. Direct determinations of σ_{coh} by mirror techniques will be described.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] L. A. Rayburn and E. O. Wollan, Oak Ridge National Laboratory, 1164, 34 (1951).

G10. Neutron Time-of-Flight Spectrometer with Betatron Source. M. L. YEATER AND E. R. GAERTTNER, *Knolls Atomic Power Laboratory,** AND G. C. BALDWIN, *General Electric Research Laboratory.*—The 100-Mev betatron at Schenectady is being used as a neutron source for the measurement of neutron cross sections by the time-of-flight method. Approximately 10^{10} neutrons per second are produced in a thick natural uranium target mounted inside the betatron doughnut in pulses having a full width at half maximum intensity of 0.35 microsecond. A moderator is also placed inside the betatron doughnut, partly surrounding the uranium. Shielding consists of water tanks in front of the betatron. Tanks packed with sodium metaborate and boron carbide make up the collimating sections between the shield and the detector. With a BF_3 ionization chamber detector, the background is approximately 1 percent of the open-beam intensity. (Scintillation counter detecting equipment is described in an accompanying paper). Timing equipment consists of a delay and 64-channel analyzer. The "zero time" signal is the output of a photomultiplier energized by x-rays from the uranium target. The resolution with a 7-meter flight path is approximately 0.1 μsec/m at 1000 ev. Measurements will be described.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

G11. Measurement of Neutron Capture Resonances using an (n, γ) Scintillation Detector. R. D. ALBERT AND E. R. GAERTTNER, *Knolls Atomic Power Laboratory.**—Neutron capture gamma-rays are detected by a pair of toluene-terphenyl liquid scintillators connected in coincidence. The scintillators are in the form of cylindrical volumes as defined by thin-walled aluminum containers. Each container is a cylindrical vessel six inches in length and eight inches in diameter with a four-inch diameter axial opening for the neutron beam which passes first through one, then the sample foil position, then the other all centered on a common axis. Each of the chambers has four RCA 5819 photomultipliers viewing its interior. The foil sample is located midway between the two chambers in a plane transverse to the beam and is seen with a solid angle of 40 percent of the total by each detector. Under actual operating conditions the counting efficiency of each counter is about 5 percent at a coincidence resolving time of 10^{-8} second. The counting efficiency is determined from the ratio of coincidence to single counting rate for Co^{60} gamma-rays. The background counting rate is less than one-tenth the total counting rate at exact resonance for the 4.9 electron-volt gold resonance when operated with the betatron velocity selector. Its use as a high resolution detector with the velocity selector and some of the results obtained will be discussed.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

G12. Neutron Detectors for the Brookhaven Fast Chopper.* H. PALEVSKY, N. G. SJÖSTRAND,† AND D. J. HUGHES, *Brookhaven National Laboratory.*—Investigations have been made of various possible neutron detectors for use with the Brookhaven fast neutron chopper. This machine is a time-of-flight neutron spectrometer that covers the energy range from about 10 volts to 5 kev. It is now operating with a burst time of 1 μsec (full width at half maximum) and shortly should give ½ μsec bursts of neutrons. The detector must have high efficiency, low gamma-ray sensitivity, and a time uncertainty of less than ½ μsec. This time uncertainty implies that the detector must be fast and small enough so that the neutron flight time in the counter is short. A pulse counting $B^{10}F_3$ ion chamber has been constructed and tested; a multiple $B^{10}F_3$ proportional counter array is now being constructed. For both, the size limitation decreases the attainable efficiency. Preliminary tests have been made with several possible types of scintillation counters, for which the use of neutron sensitive solids offers the possibility of high detection efficiency and small size. However, the gamma-ray sensitivity sets the limit for these detectors. Arrangements for which the boron disintegration alphas and the U^{235} fission neutrons are detected have been tried.

* Work carried out under contract with the U. S. Atomic Energy Commission.
† Guest physicist from AB Atomenergi, Stockholm, Sweden.

G13. Construction and Properties of Liquid Scintillation Neutron Counters. G. THOMAS AND L. BOLLINGER, *Argonne National Laboratory*.—The properties of several liquid scintillation neutron detectors containing methyl borate[1] have been determined, and the best model is now being used in the laboratory. It is a coincidence counter consisting of a quartz cell 4 in. long and 2 in. in diameter between two RCA 5819 photomultiplier tubes. The cell has a magnesium oxide-Zapon mixture as a reflecting surface and is filled with 4 g/l 2,5-diphenyloxazole, 16 mg/l diphenyl-hexatriene in equal volumes of methyl borate and phenylcyclohexane. The pulse-height distribution of the counter has been measured over the full pulse-height range. The shape of this distribution suggests that the average number of electrons is very small. Further analyses, using the measured single to coincidence rate, confirm this belief. For the best counter the average number of electrons per photocathode is 2.3. The efficiency of the counter has been measured as a function of neutron energy over the range from 0.02 to 5000 ev and found to be 75 percent for thermal and 30 percent for one-kev neutrons.

[1] C. O. Muehlhause and G. E. Thomas, Jr., Nucleonics **11** (January, 1953).

G14. Application of a Liquid Scintillation Neutron Detector to Time-of-Flight Spectroscopy. L. M. BOLLINGER, G. E. THOMAS, AND R. R. PALMER, *Argonne National Laboratory*.—A liquid scintillation neutron counter containing methyl borate has been used as the detector for transmission measurements with the Argonne fast neutron velocity selector. The high efficiency of the scintillation counter makes it feasible to use a 40-meter neutron flight path, resulting in an over-all resolution of 0.13 μsec/meter (full width at half-maximum) for our instrument. Second-order effects due to the long flight path are small because the counting rate varies as neutron velocity times a chopper cut-off function. The primary drawback of the new counter is its sensitivity to γ-rays, which results in a high background counting rate. A study of the source of the background and our efforts to reduce it are discussed. Because the counting rate of chopper neutrons varies as $\sqrt{E}$, the high background sets a lower energy limit for use of the liquid counter. This limit is about 200 ev for full speed operation. An upper limit, at about 20 kev, is set by the resolution of the system. Results of transmission measurements on several elements are given for this energy range to demonstrate the usefulness of the liquid counter.

G15. The Moderation of Ra-Be Neutrons in Limestone. J. TITTMAN AND F. F. JOHNSON, *Schlumberger Well Surveying Corporation*.—The spatial distribution of In resonance neutrons about a 1 g Ra-Be source has been measured in limestone. The moderating medium consisted of limestone blocks (density 2.72 g/cm³) stacked to form a cube 5 ft on an edge. A centrally located hole was drilled for positioning the source, and slots were milled in several of the blocks to allow insertion of the Cd covered In foils. Standard foil counting technique was used to establish the 54 min saturation activity $A_s(54)$. Corrections were applied for spatial variations in the following effects: 4.5 hr activity induced by inelastic scattering,[1] 54 min activity due to kilovolt region neutrons,[2] Cd overlap of the In 1.46 ev level,[1] and edge effects. For $600<r^2<4500$ cm² the data are fit very well by a Gaussian slowing down density corresponding to an effective Fermi age $\tau=458\pm16$ cm². At $r^2<600$ cm² the resonance neutron density lies above the Gaussian and requires a two group analysis. The two groups are split roughly 90 percent–10 percent, the latter $\tau\sim30$ cm².

[1] C. W. Tittle, Nucleonics **8**, No. 6, 5; **9** No. 1, 60 (1951).
[2] Roberts, Hill, and McCammon, Phys. Rev. **80**, 6 (1950).

THURSDAY AFTERNOON AT 2:00

Wardman Park, Burgundy Room

(GREGORY BREIT presiding)

Theoretical Physics (Nuclear Reactions and Scattering)

H1. Half-Widths and Level Shifts of One-Body Resonances. J. L. MCHALE AND JOHN L. JOHNSON, *Yale University*.*—Half-widths Γ of one-body resonances are studied for protons incident on light nuclei using the relation[1]

$$E/\Gamma\simeq k\int_0^R|\mathfrak{F}_L|^2dr+[(G_L{}^2E/k)(\partial/\partial E)(kG_L'/G_L)]_{r=R};$$
$$E=E_0 \quad \text{and} \quad R\geq b.$$

The notation is that used in the Coulomb tables[2] with b the channel radius and E_0 the energy corresponding to a phase shift $K_L=90°$. Methods of evaluating the second term on the right and approximations which neglect this term are discussed. Level shifts[3] arising from the assumption that $K_L=90°$ at resonance are presented. Provided the level shift is relatively unimportant, the approximation $E/\Gamma\simeq k\int_0^R|\mathfrak{F}_L|^2dr$ is found reasonably good if R is the classical turning point. On the other hand, the case $R=b$ which neglects the tail of the wave function in the incident channel leads to serious errors.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] G. Breit and E. P. Wigner, Phys. Rev. **49**, 519 (1936).
[2] Bloch, Hull, Broyles, Bouricius, Freeman, and Breit, Revs. Modern Phys. **23**, 147 (1951).
[3] G. Breit, Phys. Rev. **58**, 506 (1940).

H2. Influence of Extranuclear Fields on γ-γ Directional Correlations. F. COESTER, *State University of Iowa*.—The γ-γ directional correlation function for a solid source can be written in the form

$$W(\vartheta)=\sum_k a_kG_kP_k(\cos\vartheta),$$

which is the correlation function for bare nuclei if $G_k=1$. In deriving this expression a powder source has been assumed; that is, an average has been taken over all orientations of the crystal lattice. Some general properties of the attenuation coefficients G_k have been investigated. The results are the same whether one considers a direct interaction of the nucleus with the crystal field or a strong interaction of the crystal field with the electron shell and a weaker interaction of the nucleus with the electron shell. Either the magnetic moment or the electric quadrupole moment of the nucleus may be responsible for the interaction. For sufficiently long lifetime of the intermediate state, G_k approaches a minimum value. $(G_k)_{\min}=1/2k+1$ for magnetic interaction. $(G_k)_{\min}\geqq1/2k+1$ for quadrupole interaction with a field having axial symmetry. Even if there is no axial symmetry $G_2\geq1/5$. In all cases $G_0=1$, $G_k\leq1$. These results show that the mechanism con-

sidered here cannot explain the complete disappearance of the angular correlation from Cd^{111} in ionic crystals.[1]

[1] Aeppli, Frauenfelder, and Walter, Helv. Phys. Acta **24**, 335 (1951).

H3. Production and Detection of Polarized Particles in Nuclear Reactions.* A. SIMON AND T. A. WELTON, *Oak Ridge National Laboratory.*—A general calculation of the polarization resulting from nuclear reactions has been made by means of the S matrix and Racah formalisms. All sums over magnetic quantum numbers are performed; and the resulting polarization is expressed as a series in associated Legendre polynomials, each coefficient being manifestly real. All selection rules follow immediately from the requirements for the nonvanishing of the Racah and X coefficients. The only restriction required is to a two-body breakup. Higher spin tensor moments are required for the complete specification of the state of polarization of a beam of particles of spin greater than $\frac{1}{2}$. A general expression has been obtained for arbitrary spin moments resulting from a nuclear reaction. The result is expressed as a series in the spherical harmonics with all coefficients being manifestly real. The previous results of Blatt and Biedenharn for the angular distribution follow as a special case of the result. A generalization of the Eisner-Sachs rules for the complexity of angular distributions also follows.

A general expression for the tensor moments arising from two reactions in sequence will be given. This constitutes the complete solution of the detection problem.

* This paper is based on work performed for the U. S. Atomic Energy Commission at the Oak Ridge National Laboratory.

H4. Theory of (d,p) Reactions. E. GERJUOY, *University of Pittsburgh.*—Butler's theory[1] of (d,p) reactions can be simplified and made more comprehensible by use of Standard Green's function techniques. In particular, the following results are obtained: (1) Incorporating Butler's assumption as Huby[2] does leads to a Schrödinger equation which is solved exactly by $\Psi=\psi_0-GV_{NP}\psi_D$, where ψ_D is the incident deuteron wave, $(H-E)\psi_0=0$, $(H-E)G=1$, 1 the unit operator, ψ_0 has the same incoming part as ψ_D, and $V_{NP}=0$ for $r_N<a$, inside the nucleus. This expression leads by elementary manipulations without further approximation to the matrix element $\psi_f^*V_{NP}\psi_D$, ψ_f the final state with neutron captured, and thence to Butler's result. (2) The principal assumption making possible this exact solution of the problem is neglect of V_{NP} in the scattered wave[2] for $r_N>a$. Without this assumption, the integral equation for the problem yields the matrix element $\psi_f^*V_{NP}\Psi$, $V_{NP}\neq 0$ for $r_N<a$. In Born approximation, $\Psi=\psi_D$, $\psi_f^*V_{NP}\psi_D=\psi_f^*V_{NP}\psi_D$, the matrix element of Daitch and French.[3] The matrix element is always obtained from $\lim_{r_P\to\infty}\varphi_N^*\Psi$, $\varphi_N(r_N)$ a bound neutron state. Some other results will be discussed.

[1] S. T. Butler, Proc. Roy. Soc. **A208**, 559 (1951).
[2] R. Huby, Proc. Roy. Soc. (London) **A215**, 385 (1952).
[3] P. B. Daitch and J. B. French, Phys. Rev. **87**, 900 (1952).

H5. Reduced Widths in Stripping Processes.* R. G. THOMAS, *Los Alamos Scientific Laboratory.*—The deuteron stripping theories,[1] which have provided information regarding spins and parities from relative angular distributions, also indicate that the absolute yields are proportional to the same type of reduced widths γ^2 for the captured particle as occur in resonance theory. We have determined the γ^2 from published stripping yields involving light nuclei. In the case of the low levels of C^{13} and O^{17}, they are compared with those deduced from resonance theory, and found to be from two- to four-times too small. This discrepancy, which we cannot ascribe to the neglect of the overlap integral from within the nucleus, is presumably due to the inadequacy of the Born approximation. The γ also enter as dominant factors in the theory of those processes in which groups of particles, such as deuterons or tritons, may be considered as simply exchanged between colliding nuclei. The angular distributions appear in general as a sum of terms proportional to $P_L(\cos\theta)$, where θ is the angle between the momentum transfer vectors, each of which has the characteristic stripping distribution and contains the γ and Racah coefficients as factors. The conditions for the nonvanishing of these terms are similar to those of the resonance theory.[2]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] P. B. Daitch and J. B. French, Phys. Rev. **87**, 900 (1952).
[2] J. M. Blatt and L. C. Biedenharn, Revs. Modern Phys. **24**, 258 (1952).

H6. Angular Distributions from (n,p) Nuclear Reactions. N. AUSTERN AND S. T. BUTLER, *Cornell University,* AND H. MCMANUS AND W. T. SHARP, *Chalk River Laboratories.*—It has been shown that angular distributions from (n,p) reactions should evidence sharp maxima near the forward direction which arise from neutrons with large impact parameters interacting with protons out in the "tails" of the initial nucleus. The positions of these peaks are characterized by the allowed values of orbital angular momenta l_n with which the neutron can be captured to form the final state. A study of such distributions therefore may well lead to information concerning spins and parities of nuclear energy levels, as in the case of stripping reactions. In order that the maxima produced by the above mechanism stand out above the contributions due to compound nucleus formation, it is probably necessary that the incident neutron energy not be near a resonance of the compound nucleus. It would also help if the initial nucleus were sufficiently heavy for the Coulomb barrier experienced by protons in the core of the nucleus to appreciably reduce the contributions from compound nucleus formation.

H7. A New Method for the Calculation of Nuclear Phase-Shifts from Cross-Section Measurements.* HARRY LUSTIG AND JOHN M. BLATT, *University of Illinois.*—The calculation of phase shifts from experimental data has usually involved "matching" of differential cross-section data at a number of angles equal to the number of assumed nonzero phase shifts, followed by minimization of the errors at other angles. It is possible to derive n simultaneous equations for n assumed phase shifts by calculating n "moments" of a suitable expression for the differential cross section. We have derived such a theoretical expression for the problem of elastic scattering of charged particles with channel spin $\frac{1}{2}$ and performed the integrations. Cross-section data are to be integrated numerically. Then n simultaneous equations are obtained which may be solved for n phase shifts. We have applied this method to the scattering of protons by alphas[1] and compared our results with those obtained by the "matching" method.

* Supported by the U. S. Office of Naval Research.
[1] W. E. Kreger, dissertation, University of Illinois (1952).

H8. Theory of Total Neutron Cross Sections. H. FESHBACH, C. E. PORTER, AND V. F. WEISSKOPF, *Massachusetts Institute of Technology.*—We have calculated the total neutron cross sections of nuclei on the basis of the following model: The nucleus is represented by a "complex" potential well: $V(r)=-V_0(1+i\zeta)$ for $r<r_0A^{\frac{1}{3}}$, $V(r)=0$ for $r>r_0A^{\frac{1}{3}}$. The real part is the potential which usually serves as a basis for the shell model; the imaginary part represents an absorption of neutrons within nuclear matter and describes the formation of the compound nucleus. We can reproduce the measurements of Barschall and co-workers[1] made with neutrons between 0 and 3 Mev with the following choice of constants: $V_0=20$ Mev, $r_0=1.45\times10^{-13}$ cm, $\zeta=0.05$. This value of ζ means that a neutron must penetrate a length 2×10^{-12} cm through nuclear matter before it forms a compound nucleus. Hence, neutrons of this energy seem to show a relatively small interaction with the other nucleons in a nucleus.

[1] H. H. Barschall, Phys. Rev. **86**, 431 (1952).

H9. Scattering Approximations for the Transparent Nucleus Model. J. MAYO GREENBERG, *Rensselaer Polytechnic Institute.*—It has been shown[1] that the optical model of the nucleus gives a good account of the scattering of high energy ($E \gtrsim 100$ Mev) nucleons by medium to heavy nuclei. However there seem to be sufficient ambiguities in the validity of the theoretical scattering approximations to warrant some further investigation. For the scattering by a square well potential, the Born approximation should be valid if the parameter $y = k_0R(m-1) \lesssim 1$, where k_0 is the propagation constant, R is the radius of the well, and m is the effective index of refraction. For the cases under consideration m is very close to unity but k_0R may be quite large. There are two approximations which, for the above conditions, should give appreciably better results than the Born approximation. One of these has already been applied to neutron scattering (nucleus considered as a square well), but it may be extended[2] to include Coulomb effects for protons. The other method is the soft sphere approximation.[3] A comparison will be made between the three approximations.

[1] Fernbach, Serber, and Taylor, Phys. Rev. **75**, 1352 (1949).
[2] R. Glauber, private communication.
[3] E. W. Montroll and J. M. Greenberg, Phys. Rev. **86**, 889 (1952).

H10. Elastic Scattering of Protons by Nuclei.* F. ROHRLICH AND D. M. CHASE, *Princeton University.*—Extensive calculations on the elastic scattering of protons by various elements were carried out. The optical model was tested in the 20 Mev region. Inside the nucleus a complex potential of square well shape was assumed, outside a Coulomb potential. Exact solutions for the differential cross section yield the following results: (1) The Feshbach-Weisskopf boundary condition model, within its range of validity, gives approximately the same results as the exact complex square well, but leads to a smoother angular distribution. (2) Parameters consistent with the transparency model at high energies agree with experiments on light elements (Al), except for backscattering, which is about twice the experimental value. For heavier elements the agreement becomes progressively worse. The above parameters give constructive interference with Rutherford scattering, whereas for $Z > 30$ the experiments show increasing destructive interference. (3) The results are quite insensitive to variations of the relevant parameters. Also, the well shape does not seem to be responsible for the main discrepancies. Absorption is essential, but the well depths may be considerably smaller than estimated from high energy data and current nuclear models. Further results and their physical implications will be discussed.

* This work was supported in part by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

H11. Elastic Scattering of Particles by Atomic Nuclei.* NORMAN C. FRANCIS AND KENNETH M. WATSON, *Indiana University.*—The so-called "optical model" has been frequently employed in the study of the elastic scattering of fast particles by atomic nuclei. Here the nucleus is replaced by a potential well to describe the interaction with the incident particle. It is shown that this procedure is generally valid, even for low energies, provided that the "potential well" is generalized to include spin-orbit couplings. The evaluation of the potential well involves solving an integral equation, from which a Lorentz-Lorenz type formula can be obtained for nuclear matter, for instance. These considerations are applied to a discussion of the deuteron stripping reaction and lead to a correction to the Butler[1] angular distribution (a correction which arises from the diffraction scattering of incident and outgoing particles).

* Supported in part by a grant from the National Science Foundation.
[1] S. T. Butler, Proc. Roy. Soc. (London) **A208**, 55 (1951).

H12. Neutron-Proton Scattering. EARLE LOMON* AND HERMAN FESHBACH, *Massachusetts Institute of Technology.*—A model first proposed by Breit is applied to neutron-proton scattering. It is assumed that the neutron-proton force can be represented by a boundary condition $(r\psi)' = T\psi$ where T is an energy independent operator, and the condition is applied at a fixed interparticle distance r_0. T is a constant for singlet states and involves the tensor operator S_{12} for triplet states. The effective ranges and scattering lengths determine T and r_0 for singlet and triplet even states. The odd state T's (r_0 is the same as in even states) are determined by the requirement that the angular distribution be almost symmetric about 90° at 40 Mev. The solution which implies strong repulsion in the triplet odd states as well as the Serber solution is found. Employing the former, excellent agreement with the experiments for both angular distribution and total cross section is obtained up to 150 Mev. The agreement at 260 Mev is excellent at 90°, but there is not a sufficiently large cross section at 180°. The tensor forces are found to have nearly negligible effects in this energy range.

* On Quebec Postgraduate Scholarship.

H13. A Phase-Shift Analysis of High Energy *p-p* Scattering. J. BENGSTON AND R. M. THALER, *Yale University.**—The high energy (100–350 Mev) proton-proton scattering data are analyzed in terms of s-waves and p-waves alone. For a non-central interaction the phase shifts for $^3P_0$, $^3P_1$, $^3P_2$ are in general different from each other. The scattering cross section for such a case has been given by Breit, Kittel, and Thaxton.[1] If the phase shifts for $^1S_0$, $^3P_0$, $^3P_1$, $^3P_2$ are treated as free parameters, there is more than sufficient latitude to fit the high energy data in a manner such that the phase shifts vary smoothly with energy and join smoothly to lower energy fits.[2] Smooth fits can be found for which the phase shift for $^3P_2$ is greater than those for $^3P_0$, $^3P_1$ over the entire energy range, corresponding to inversion of ^3P_j levels. Likewise, there are fits which in addition to meeting above criteria are not in contradiction with the hypothesis of charge independence.

* Assisted by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
[1] Breit, Kittel, and Thaxton, Phys. Rev. **57**, 255 (1940).
[2] See Yovits, Smith, Hull, Bengston, and Breit, Phys. Rev. **85**, 540 (1952).

H14. Effect of $^3P_2 - {}^3F_2$ Coupling on *p-p* Scattering. R. M. THALER, J. BENGSTON, AND G. BREIT, *Yale University.**—Since there is no general reason for regarding the orbital angular momentum L and the total spin as good quantum numbers the coupling of $^3P_2$ to $^3F_2$ is calculated. To avoid arbitrariness an isobaric state is used in scattering matrix formalism[1] with angular momentum 2 having widths Γ_L. Fits to experiment[2] at 240 Mev are used as typical. For no coupling ($\Gamma_L = 0$) and admitting only S, P, D, $^3F_2$ anomalies the phase shifts $\delta_{0,1,2}$ of $^3P_{0,1,2}$ are only partially determined by data but $\delta_2 < 0$ for $T = (\Gamma_1 + \Gamma_3)/(E_R - E) > 0.1$ and $T < 0.3$ for all fits with $^1K_0 \approx 31°$, $^1K_2 > 0$. Limits on T depend on choice of $^1K_0$. Successful fits have been found only with "regular" order of the δ, but no reason for excluding the inverted order has been found. The flatness of the (σ, E) curve at large angles and the rise of σ at small angles are qualitatively reproduced.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] G. Breit, Phys. Rev. **58**, 1068 (1940).
[2] O. A. Towler, Phys. Rev. **85**, 1024 (1952).

H15. Role of a Nucleon Isobar in High Energy Interactions. BERNARD T. FELD, *M.I.T.*—The successful application of the concept of a nucleon isobar (or ordinary and isotopic spin $\frac{3}{2}$) to describe the fundamental nucleon-meson interactions (scattering, photoproduction, production in nucleon-nucleon collisions) suggests the possibility of invoking the concept for other and more complicated nuclear interactions. Thus, Drell (private communication) has pointed out the applicability to

the so-called "elastic" photoproduction of neutral mesons by complex nuclei, and Austern[1] has considered the photodisintegration of the deuteron from this point of view. Various aspects of these and other reactions have been considered from a completely phenomenological point of view, using only measurements on the fundamental interactions to establish the interaction parameters. In the case of nucleon-nucleon scattering, the excitation of a nucleon isobar can lead to an appreciable cross section, but the angular distribution, as predicted from this simple approach has strong forward and backward maxima.

[1] N. Austern, Phys. Rev. **87**, 208 (1952).

THURSDAY AFTERNOON AT 2:00

Shoreham, Main Ballroom

(R. F. BACHER presiding)

Divers Topics in Nuclear Physics

I1. Equilibrium Proton Charge Ratios from Charge Exchange in Various Materials.* J. A. PHILLIPS, *Los Alamos Scientific Laboratory.*—Measurements have been made of the ratio of the positive, neutral, and negative components of a proton beam of energies 4–140 kev passing through thin foils. The emergent beam is collimated, analyzed by a magnetic field, and the intensity of the components measured by a phosphor photomultiplier. A liquid air trap surrounds the exit side of the foil, and fresh layers of material can be evaporated onto the foil. Very thin layers of material ($\sim$10 atoms thick) are required for equilibrium charge ratios to be established. The neutral and positive components are equal at 36 ± 3 kev proton energy for the following surface materials, Al, Al_2O_3 and/or contaminations, Au and SiO. At 5 kev the percentages of the neutral and negatively charged components are, respectively; Al 84, 5.6; Al_2O_3 and/or contaminants 80, 3.8; SiO 80, 3.5; and Au 83, 4.5. At 140 kev the corresponding figures are, Al 5.2, 0.09; Al_2O_3 and/or contaminants 9.9, 0.02; SiO 8.8, 0.02; and Au 13.9, 0.04.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

I2. Direct Measurement of the Nuclear Absorption of X-Rays.* H. W. KOCH AND R. S. FOOTE, *National Bureau of Standards.*—The nuclear absorption of x-rays from a betatron operating at 30 Mev has been measured directly for carbon[1] and copper. The technique employed good geometry, the maximum tolerable number of absorber mean free paths (4 to 8.5), and an x-ray spectrometer with high detection efficiency and good energy resolution. Carbon absorbers 5 cm in diameter, up to 306 cm long and an absorber 25 cm in diameter and 30 cm long were used. The x-ray cone was 0.06 degrees. The source to spectrometer distance was 935 cm. The detector was a calibrated NaI total absorption spectrometer.[2] The pulse-height spectrum produced by x-rays transmitted by a particular absorber was analyzed and showed marked depressions in intensity due to nuclear absorption. The percentage intensity change is proportional to the absorber length and to the ratio of nuclear to electronic absorption. The maximum length is limited by the geometry. The copper results give one nuclear absorption peak at approximately 18 Mev as expected. The carbon data show pronounced nuclear absorption peaks below 20 Mev.

* Supported by the Office of Scientific Research of the Air Research and Development Command.
[1] Recent results on cabon using activation curve data are to be found in a paper by Haslam, Horsley, Johns, and Robinson (to be published).
[2] M. Cleland and H. W. Koch, Phys. Rev. **86**, 588 (1952).

I3. Bremsstrahlung from P^{32} Betas. M. GOODRICH, J. S. LEVINGER, AND W. PAYNE, *Louisiana State University.*—Wyard[1] has calculated an approximate energy distribution for bremsstrahlung produced by P^{32} betas stopped in brass. We have made preliminary measurements of the pulse distribution in a NaI crystal due to these bremsstrahlung. We have calculated the pulse distribution using Wyard's photon spectrum, Bell's data[2] on the efficiency and pulse distribution for mononergetic gammas, and corrections for absorption and degradation in the brass. The experimental and calculated curves agree within 15 percent for photon energies from 50 to 550 kev. The preliminary experiment shows peaks at 600 and 1300 kev which are probably due to radioactive impurities.

[1] S. J. Wyard, Proc. Phys. Soc. (London) **A65**, 377 (1952).
[2] P. R. Bell (private communication).

I4. Annihilation of Positrons in Solids.* T. A. POND, *Princeton University.*—Bell and Graham suggest that about 30 percent of the positrons stopped in "amorphous" solids annihilate via triplet positronium.[1] Their data indicate that 0.7 percent of the annihilations in Teflon will be three-photon, provided the triplet lifetime is unchanged. In this experiment a positron source, Na^{22} mounted between aluminum foils of about 75 percent transmission, is enclosed on both sides by sandwiches of aluminum and Teflon, each layer thick enough to stop the positrons. Two-photon coincidences are taken with Teflon and aluminum alternately next to the foils. NaI(Tl) scintillators are used. To give geometry independent of positron range, one is collimated to an area smaller than the crystal but much larger than the source, while the other subtends a much larger solid angle. To check identity of gamma-scattering when the sandwiches are reversed, sufficient aluminum to stop the positrons is interposed between the source and the sandwiches. Within statistics there is no asymmetry in the rates under these circumstances. Present data indicate about $\frac{1}{2}$ percent more two-photon annihilations in aluminum than in Teflon. Further results will be discussed.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] R. E. Bell and R. L. Graham, Phys. Rev. (to be published).

I5. Annihilation of Fast Positrons in Flight.* J. B. GERHART, R. SHERR, AND B. C. CARLSON, *Princeton University.*—The weak continuous spectrum of hard γ-rays resulting from the stopping of positrons in various materials has been investigated with a NaI(Tl) scintillation spectrometer. Measurements were made chiefly in the γ-ray energy interval from 511 kev to 1.3 Mev for the continuous β-spectra of Ne^{19} and A^{35} (maximum positron energy of 2.2 and 4.4 Mev, respectively). The geometry was chosen to ensure averaging of the annihilation spectrum over all angles. Theoretical spectra were calculated for Lucite, brass, and lead as the stopping materials. Comparison with experiment on an absolute basis is made possible through the knowledge of the spectrometer efficiency as a function of energy. The calculations include bremsstrahlung and single-quantum annihilation as well as two-

quantum annihilation. In the case of lead the experimental spectra are in good agreement (10 percent) with the calculations for both Ne^{19} and A^{35}. For brass and Lucite the calculations predict roughly 30 percent less hard radiation than was observed, the discrepancy being greater for A^{35} than for Ne^{19} and greater for Lucite than for brass. (In view of the uncertainty in the bremsstrahlung calculations, the agreement for lead may be fortuitous.)

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

I6. Electron Cyclotrons (Microtrons) for *X* and *K* Band Operation. H. F. KAISER, *Naval Research Laboratory.*—In a previous paper[1] the author pointed out the possibilities in producing compact high energy electron accelerators by scaling the microtron[2-4] for higher frequency operation and described results obtained with a preliminary 3 cm, 1.3-Mev microtron. Further results obtained with this and another 3 cm, 3.2-Mev microtron now under development for operation as a sealed-off unit will be presented and also some work on a microtron for *K* band frequency operation.

[1] H. F. Kaiser, Phys. Rev. **87**, 183 (1952).
[2] V. Vekaler, Compt. rend. **43**, 329-331 (1944).
[3] Henderson, LeCaine, and Montalbetti, Nature **162**, 699-700 (1948).
[4] Henderson, Heymann, Jennings, Proc. Phys. Soc. (London) **66**, 41-49 (1953).

I7. Field Inhomogeneities in Alternating Gradient Synchrotron.* E. D. COURANT, *Brookhaven National Laboratory.*—If in the alternating gradient synchrotron[1] the individual magnet sectors are misaligned or their field strengths vary, the particle orbits will be displaced from the center of the vacuum chamber. The orbit displacement can be infinite (linear approximation) if the frequency of oscillations around the equilibrium orbit is an integral multiple of the frequency of revolution (resonance case); otherwise it is finite. The orbit displacement may be estimated by a modified Fourier analysis of the misalignments, using as the basic functions the eigenfunctions of Hill's equation. A conventional Fourier analysis leads to similar results and is a usable approximation. It is found that, when the frequencies are well away from resonance, the maximum orbit displacement is of the order of 20 times the rms misalignment of individual magnet sectors with typical design parameters.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] Courant, Livingston, and Snyder, Phys. Rev. **88**, 1190 (1952).

I8. Operation of an Electromagnetic Electron Beam Extractor.* R. S. FOOTE AND BEN PETREE, *National Bureau of Standards.*—The electron beam of a 50-Mev betatron has been removed from the donut by the use of a pulsed electromagnetic extractor.[1] The extractor consists of an array of eighteen parallel wires through which is passed a 1.8 microsecond half-sine wave current pulse. A peak amplitude of 3300 amperes is sufficient to remove 50-Mev electrons. The current pulse removes the beam by creating a sharp step in the magnetic guiding field at the time that the electron orbit is expanded. The extractor is located in the magnetic field at a radius near where $n=1$, and produces a localized region where the resultant field is approximately zero. The electrons move tangentially to the orbit through this region and emerge in the fringing field of the magnet. Initial tests at 11 Mev have checked the operation of the equipment. Minor circuit improvements are being made to increase this energy. Photographs show the beam is well-defined as it emerges from the donut through a thin window. The design of the extractor, associate circuitry and removal efficiencies will be discussed.

* Supported by the U. S. Atomic Energy Commission.
[1] R. S. Foote, National Bureau of Standards Report 1001.

Invited Papers

I9. Photodisintegration of the Deuteron. WILLIAM WOODWARD, *Cornell University.* (30 min.)
I10. Experimental Results on Nuclear Reactions in Stars. W. A. FOWLER, *California Institute of Technology.* (30 min.)

THURSDAY AFTERNOON AT 2:00
Shoreham, West Ballroom
(W. F. MEGGERS presiding)

Optical Spectra: X-Rays

IA1. Approximate Hartree Type Wave Functions and Matrix Elements for *K* and *L* Shells of Atoms and Ions. R. E. MEYEROTT, *Argonne National Laboratory.*—Approximate Hartree wave functions have been computed and used to compute the dipole elements between the *K* and *L* shells of atoms and the continuum. If $I_{nl}^{\eta l'}=\int_0^\infty R_{nl}rR_{\eta l'}dr$, this matrix element can be expressed approximately in the following form $I_{nl}^{\eta l}={}^{H}I_{nl}^{\eta l'}+a_{nl/Z}{}^{\eta l'}+b_{nl/Z^2}{}^{\eta l'}$, where ${}^{H}I_{nl}^{\eta l'}$ is the hydrogen-like dipole matrix element. The a's and b's are given in the table. These matrix elements have been used to compute photoelectric mass absorption coefficients. Comparison will be made with experimental data.

η	${}^{H}I_{1s}{}^{\eta p}$	$a_{1s}{}^{\eta p}$	${}^{H}I_{2s}{}^{\eta p}$	$a_{2s}{}^{\eta p}$	$b_{2s}{}^{\eta p}$
0.00	1.5311	2.923	4.6888	62.37	−737.6
0.25	1.0137	1.384	1.5463	6.769	−215.4
0.50	0.7201	0.7374	0.77891	1.085	+ 10.06
1.00	0.4162	0.2611	0.31669	−0.0428	+ 11.26

η	${}^{H}I_{2p}{}^{\eta s}$	$a_{2p}{}^{\eta s}$	$b_{2p}{}^{\eta s}$	${}^{H}I_{2p}{}^{\eta d}$	$a_{2p}{}^{\eta d}$	$b_{2p}{}^{\eta d}$
0.00	1.3535	28.82	−278.5	5.4142	99.50	11.81
0.25	0.39925	4.198	−204.7	1.2629	9.902	73.7
0.50	0.18359	1.022	− 83.0	0.51928	2.307	39.5
1.00	0.08268	−2.292	− 22.3	0.16354	−0.255	46.5

IA2. Configuration Interaction in Mo II. HOWARD D. GOLDGRABER,* *University of Pennsylvania.*—The analysis of the even terms in Mo II by Kiess[1] gives the sextet and the four quartets in the $4d^5$ configuration and the sextet and five low quartets in the $4d^45s$ configuration. The observed term positions were compared with the theory and, in accord with previous results for the iron group elements, the adding of a correction proportional to $L(L+1)$ as an extra parameter is found to improve markedly the agreement between theory and experiment in the $4d^5$ configuration. The inclusion of the effect of the interaction of the $4d^5$ and $4d^45s$ configurations is found also to improve the agreement; the value of H_2 ($=R^2(dd,ds)/35$) is estimated as 240 cm^{-1}, which is approximately twice the value of H_2 in Cr II, the homologous element in the iron group region. The positions of the unknown terms are predicted. The intervals of the terms of the $4d^5$ configuration were calculated using the d^5 spin-orbit matrix, and the small effect of configuration interaction on the interval structure is estimated.

* Now at the Forrestal Research Center, Princeton University.
[1] C. C. Kiess (private communication).

IA3. Isotope Shift in Doubly Ionized Boron.* EDWARD W. BURKE,† *University of Wisconsin.*—The isotope shift in the resonance transitions ($2s\,^2S-2p\,^2P$) of the spectrum of B III has been studied spectroscopically using separate isotopes. The excitation was effected with a low voltage condensed spark in a hollow cathode tube. The value of the total shift has been tentatively determined at about 1.7 cm^{-1}, in the same direction as the normal shift.

* Supported by the U. S. Office of Naval Research.
† On leave from King College, Bristol, Tennessee.

IA4. Isotope Shift in the Arc Spectrum of Lithium.* RAYMOND H. HUGHES, *University of Wisconsin.*—The isotope shift of the Li I transitions $2s\,^2S-2s\,^2P$ and $2p\,^2P-3d\,^2D$ is under study with the aid of separated isotopes. On the resonance lines the findings of Jackson and Kuhn[1] have been in general confirmed, except that the shift $Li^7\,^2P_{\frac{1}{2}}-Li^6\,^2P_{\frac{1}{2}}$ with respect to the centroid of the ^2S appears to be appreciably less than 0.020 cm^{-1}, and we fail to confirm the finding[1] that the $2p\,^2P$ fine-structure separation is greater in Li^7 than in Li^6. The study of both line complexes shows that, contrary to the approximate theory which calls for a specific shift only in levels whose electron configurations have l values differing by unity, there is a specific shift between $1s^22s\,^2S$ and $1s^23d\,^2D$, in the same direction as the normal shift, with a value tentatively determined at about 0.04 cm^{-1}.

* Supported by the U. S. Office of Naval Research.
[1] D. A. Jackson and H. L. Kuhn, Proc. Roy. Soc. (London) **A173**, 278 (1939).

IA5. Electric Field Gradients of Atomic p Electrons.* W. V. SMITH AND R. G. BARNES, *University of Delaware.*—As Townes and Dailey have pointed out,[1] the contributions of atomic p wave functions generally preponderate in determining the electric field gradient at the nucleus ($\partial^2V/\partial Z^2$) atom. Calculations of the contributions of p electrons to ($\partial^2V/\partial Z^2$) atom, based on the doublet fine structure $\Delta\nu$, have been made in certain cases.[1,2] In the present investigation, values of the quantity $(a_0/r)^3_{Av}$ have been evaluated for p electrons from available atomic-spectra data for about 35 elements and are presented in a graphical form allowing easy interpolation for more complicated cases. A by-product of this work is the observation that the inner atomic number Z_i is more nearly represented by $Z-n$, n being radial quantum number, than by $Z-4$, especially in the case of the lighter elements. Application of the interpolated field gradients to the cases of nitrogen and sulfur suggests that for nitrogen $(\partial^2V/\partial Z^2)_{atom}=3.2\times10^{15}$ esu and for sulfur $(\partial^2V/\partial Z^2)_{atom}=6.1\times10^{15}$ esu. These values are, respectively, about 30 percent 20 percent lower than the values estimated by Townes and Dailey, and suggest that their estimate of the nuclear quadrupole moments of N^{14} and S^{33} should be revised upwards. The estimate of $(\partial^2V/\partial Z^2)_{atom}$ for boron[2] is essentially unchanged.

* Work supported by the U. S. Office of Ordnance Research and the Research Corporation.
[1] C. H. Townes and B. P. Dailey, J. Chem. Phys. **17**, 782 (1952).
[2] H. G. Dehmelt, Z. Physik **133**, 528 (1952).

IA6. X-Ray Absorption Fine Structure with Polarized X-Rays.* R. KROGSTAD, W. NELSON, AND S. T. STEPHENSON, *State College of Washington.*—X-ray absorption fine structure is usually observed with polycrystalline absorbers and unpolarized x-rays. If one were to use a single crystal absorber and polarized x-rays, one would expect a more pronounced structure; and furthermore, if one were to vary the orientation of the single crystal with respect to the electric vector of the polarized x-rays, a shift should result in the position of the structure. This experiment has been carried out using a double crystal vacuum x-ray spectrometer in such a manner that the first crystal polarized the beam and the second crystal acted as absorber. The wavelength for the chlorine K edge was deviated 92.5° by calcite and polarization resulted. Absorption took place in NaCl or KCl single crystals so arranged that the direction of photoelectric emission could be varied with respect to prominent planes in the crystal (either perpendicular to 100 or 110 planes). A pronounced structure was observed extending out some 25 volts from the main edge. Structure within 15 volts of the main edge was independent of crystal orientation. A feature some 20–25 volts from the edge was found to be dependent upon orientation for NaCl but not for KCl. These results are discussed in the light of theory.

* Supported in part by the U. S. Office of Naval Research.

IA7. Response of Anthracene Crystals to Mono-Energetic Soft X-rays.* W. H. ROBINSON, *University of Illinois.*—The response of anthracene to mono-energetic x-rays in the range from 10 kev to 30 kev has been investigated. The mono-energetic x-rays were obtained by a method described by Insch[1] in which resonant fluorescence x-radiations are excited in suitable target materials by a more energetic primary source. The pulses from a 5819 photomultiplier were amplified by a linear, nonoverloading amplifier and analyzed with a single-channel pulse-height analyzer. The results of previous experiments[2] performed with electrons in this energy range indicated that the differential fluorescence efficiency (dL/dE) is smaller for electrons than for heavy particles of the same specific energy loss (dE/dx). The present experiment, which is not subject to the uncertainties caused by possible surface effects and back diffusion inherent in the previous work, confirms this result.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Insch, Phil. Mag. **41**, 857 (1950).
[2] Taylor, Jentschke, Remley, Eby, and Kruger, Phys. Rev. **84**, 1034 (1951).

IA8. The Absorption of Phosphorus in the Neighborhood of the $L_{2,3}$ Edge.* D. H. TOMBOULIAN, *Cornell University.*—The absorption of the red allotropic form of phosphorus has been investigated in the far ultraviolet region extending from 60 to 160A. The incident radiation consisted of high stage excitation lines of oxygen, sodium, and silicon produced in a condensed discharge in a glass capillary. The absorbers were prepared by vacuum distillation of the element on Zapon substrates. The thickness of the deposited layer ranged from 400A to 800A. By a photometric procedure described previously,[1] the absorption curve was determined from measurements carried out on a pair of absorbers which were identical except for the thickness of the phosphorus layer. The preliminary results show an absorption edge at about 94A to be identified with the $L_{2,3}$ discontinuity. No previous measurements have been reported on the absorption of phosphorus in the soft x-ray region. Skinner[2] has observed a relatively sharp edge located at 95A in the intensity distribution of the $L_{2,3}$ emission band.

* Supported by the U. S. Office of Ordnance Research.
[1] D. H. Tomboulian and E. M. Pell, Phys. Rev. **83**, 1196 (1951).
[2] H. W. B. Skinner, Trans Roy. Soc. (London) **239**, 95 (1940).

IA9. Measurements of K Edge Jump Ratios with a Linear Motion X-Ray Spectrometer. H. P. HANSON AND H. W. SCHRADER.—A single crystal x-ray spectrometer using Geiger counter recording has been constructed for x-ray measurements where high resolution is not required. The unique feature of this instrument is that the change in Bragg angle

is effected through a linear motion of the crystal rather than through a rotation. The simplicity and versatility of this instrument give it some advantages over the ordinary arrangement. Measurements have been made on various K edge jump ratios, and differences are noted between the values in the literature and the values we obtained.

Invited Paper

IA10. Zeeman Effect in Microwave Spectroscopy. C. K. JEN, *Applied Physics Laboratory, Johns Hopkins University.* (30 min.)

FRIDAY MORNING AT 9:30

Shoreham, Terrace Room

(M. A. TUVE presiding)

Atmospheric Physics

J1. Origin of Ionization in the *E* Layer of the Ionosphere.* ERNST BAUER, *New York University,* AND TA-YOU WU, *National Research Council, Ottawa.*—It is generally believed that free electrons in the E layer of the ionosphere are largely produced by the first photo-ionization of oxygen molecules by solar radiation and that they disappear by dissociative recombination. The consequences of this are evaluated, using the values for concentrations of oxygen molecules given by Moses and Wu.[1] Several models of Moses and Wu give maximum daytime electron concentrations of the order of 10^6/cc at altitudes of the order of 100 km in a layer whose thickness is of the order of 5 km. If one uses the same models to calculate the location of the region produced by the first ionization of atomic oxygen, one finds that the maximum electron concentrations are of the order of 10^5 to 10^6/cc at altitudes of the order of 150 to 200 km.

* This work was performed at Washington Square College of Arts and Sciences, New York University, and was supported in part by contract with the U. S. Air Force, through sponsorship of the Geophysics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command.

[1] H. E. Moses and Ta-You Wu, Phys. Rev. **87** 628 (1952); and abstract J3.

J2. The Propagation of Short Radio Waves Well Beyond the Horizon.* THOMAS J. CARROLL, *M.I.T.*—The eigenvalues and normalized eigenfunctions have been calculated which describe the propagation of short radio waves around a perfectly conducting earth surmounted by a finite layer of inhomogeneous air in which the index of refraction decreases from its surface value at the standard rate to unity at 30 000 feet and above. The theory of the bilinear index profile is applied directly. The calculated attenuation rates of the weak but dominant higher order modes well beyond the horizon, their absolute values, and the height gain functions fit well with long puzzling experimental observations on such fields well beyond the horizons of high power transmitters at all vhf and microwave frequencies. Conventional mode theory based on the 4/3 earth approximation neglects the weak downcoming waves set up by internal reflection in the earth's inhomogeneous atmosphere, and thus underestimates the field deep in the shadow of the earth bulge by considering refraction and diffraction alone. Omnipresence of the weak observed fields may thus be explained without assumption of atmospheric turbulence. Reliable nonoptical vhf and microwave circuits several hundred miles long are apparently possible when highest powers and antenna gains are employed.

* Supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

J3. The Dissociation and Recombination of Oxygen in the Upper Atmosphere Assuming Three-Body Recombinations.* HARRY E. MOSES, *New York University,* AND TA-YOU WU, *National Research Council, Ottawa.*—The dissociation region of oxygen molecules is treated in the same "self-consistent" manner described in a previous paper,[1] except that now the densities of atomic and molecular oxygen have been calculated as functions of the altitude, on the assumption that the main recombination process between oxygen atoms is a three-body nonradiative process. The result of the present study indicates that dissociation occurs at an altitude about 5 km higher than the corresponding altitude of reference 1. Furthermore, the region of dissociation is broader than in the model of reference 1. The maximum atomic density is $0.5\text{–}1\times10^{13}$/cm^3.

* This work was performed at Washington Square College of Arts and Sciences, New York University, and was supported in part by contract with the U. S. Air Force through sponsorship of the Geophysics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command.

[1] H. E. Moses and Ta-You Wu, Phys. Rev. **87**, 628–632 (1952).

J4. The Contribution of the 15 Micron CO_2 Band to the Earth's Radiation Balance. GILBERT N. PLASS, *The Johns Hopkins University.*—The influence of CO_2 on the radiation balance has been reinvestigated using the latest theoretical and experimental results. These calculations take account of the variation in line-width with pressure and the overlapping of the lines in the band. It is found that the earth's total radiation loss to space in the interval 12–18μ is 0.0927 cal/cm^2 min. The influence of CO_2 variations on climatic change has been considerably underestimated recently because (1) the CO_2 lines far from the band center which give the largest contribution were largely neglected; (2) the variation of half-width with pressure was not taken into account; (3) the shielding influence of the H_2O lines was overestimated. Taking account of these factors, we find that a fifty percent increase in the CO_2 concentration would increase the surface temperature 2.2°C. Considerably larger changes must have occurred during the earth's history because of the many factors that influence the CO_2 content of the atmosphere. For example, in this century man will add sufficient CO_2 to the atmosphere by burning fuels to increase the temperature measurably, if no other factors change in the CO_2 balance. CO_2 variations must be considered together with other factors in theories of climatic change.

J5. Absorption of Sound in Fogs and Emulsions. P. S. EPSTEIN, *California Institute of Technology.*—Starting from the fundamental equations of hydrodynamics, a theory of the absorption of sound by spherical obstacles was developed,

which takes into consideration losses through viscosity and through heat conduction. The theory was applied to the cases of small water droplets in air and of small air bubbles in water, within the range of acoustic frequencies from 500 to 10 000 cycles. The agreement of the calculated values with the available observations is satisfactory.

Invited Papers

J6. Recent Advances in Atmospheric Optics. J. A. SANDERSON, *Naval Research Laboratory.* (30 min.)

J7. Atmospheric Transmission of Light. C. A. DOUGLAS, *National Bureau of Standards.* (30 mins.)

J8. Physical Problems Encountered in High Speed Flight. H. H. KURZWEG, *Naval Ordnance Laboratory.* (30 min.)

FRIDAY MORNING AT 9:30

Wardman Park, Burgundy Room

(H. A. BETHE presiding)

Theoretical Physics (Nuclear Forces)

JA1. Potential Scattering at High Energies. ROY J. GLAUBER, *Harvard University.*—Scattering problems at incident energies larger than the interaction potential frequently require treatment more accurate than the first Born approximation. This is particularly so in treating the interference of waves scattered by more than a single center, since the first Born approximation omits the complex phase factors of the individual scattering amplitudes. A considerably more exact expression for the scattering amplitude has been derived by employing an approximate form of the Green's function appropriate to wave propagation at high energies and summing the complete Born series. An alternative derivation, simpler but slightly less accurate, is based on the W. K. B. treatment of the incident plane wave. The expression for the scattering amplitude is most accurate at small angles and satisfies the conditions imposed by the unitarity of the collision matrix (conservation, etc.). The total cross section is therefore immediately obtained from the imaginary part of the amplitude for forward scattering. The approximation procedure is related to a number of existing quasi-optical methods devised for particular problems and, in effect, generalizes them. Several cases to which the method has been applied will be discussed.

JA2. Causality Condition and S Matrix for Nonrelativistic Particles. N. G. VAN KAMPEN, *Institute for Advanced Study.*—For the scattering of electromagnetic radiation by a fixed center, an explicit expression for the S matrix has been derived from the condition that no scattered radiation can appear until the incident wave packet has reached the center. For a nonrelativistic particle, however, this condition cannot be used, because no incident packets exist that vanish rigorously until a certain time. We therefore reformulate the condition as follows: At any time the total probability of finding the particle outside the scattering center shall not be greater than 1, for every incident wave packet. From this follows rigorously that S, as a function of the wave number k, is analytic and holomorphic in the first quadrant and has an imaginary part ≤ 1. That suffices to give an explicit integral representation and a product expansion for $S(k)$. With the additional assumption $S(-k)=S^*(k)$ a more specific expression can be derived of the form $S(k)=e^{-2iak}\pi(1-k/a_n)(1-k/b_n)^{-1}$ (a_n zeros, b_n poles, $\alpha\leq$ radius of scattering center). Special consequences are the properties that Wigner found for the R matrix and an integral relation between real and imaginary parts of $S(k)$ (in which a series of terms corresponding to the bound states occurs).

JA3. Equivalence Theorems. P. MOLDAUER AND K. M. CASE, *University of Michigan.*—It will be shown that to the first order in the coupling constant all possible linear interactions between scalar (or pseudoscalar) mesons and nucleons either vanish or are equivalent to the scalar (or pseudoscalar) interactions which arise from the Lagrangian density coupling terms, $\sum_{i=1}^{3} g_i\varphi^{(i)}\bar{\psi}\gamma_5'\tau_i\psi$. Similarly all possible linear interactions between vector (or pseudovector) mesons and nucelons will be shown either to vanish in the first order or to be equivalent to one of two types of vector (or pseudovector) interactions which have the Lagrangian density coupling terms, $\sum_{i=1}^{3} g_i\varphi_u^{(i)}\bar{\psi}\gamma_u\gamma_5'\tau_i\psi$ and $i\sum_{i=1}^{3} g_i\varphi_u^{(i)}[(\partial\bar{\psi}/\partial x_u)\gamma_5'\tau_i\psi - \bar{\psi}\gamma_5'\tau_i(\partial\psi/\partial x_u)]$. The customary tensor interaction will be found to be equivalent to a combination of the latter two interactions. γ_5' is unity for scalar and vector mesons and is γ_5 for pseudoscalar and pseudovector mesons. $\varphi^{(1)}$ and $\varphi^{(2)}$ are the real and imaginary parts of the charged meson field (hence $g_1=g_2$) and $\varphi^{(3)}$ is the neutral meson field.

JA4. Bound States of the Meson-Nucleon System. R. ARNOWITT, *University of California,* AND S. DESER,* *Harvard University.*—Recent meson-nucleon scattering experiments have suggested the existence of an isobaric $\frac{3}{2}$ state. An investigation of the two body meson-nucleon equation is being made to find if such states occur. The Green's function for the meson-nucleon system has been set up, the corresponding wave function obeying the homogeneous equation. This equation with two times entering may be reduced down to a single time Schrödinger equation. In general, the potential occurring is an integral operator. For the lowest order interaction yielding an isotopic spin $\frac{3}{2}$ state the adiabatic approximation to the potential is a Yukawa type function with range of the order $(3.5\mu)^{-1}$. Some approximate solutions of the Schrödinger equation have been obtained. The results indicate that for the $J=\frac{1}{2}$ state neither bound nor virtual states can form. For the $J=\frac{3}{2}$ case a bound meson-nucleon state can exist for large enough values of the coupling constant.

* N. S. F. Predoctoral Fellow.

JA5. Low Energy Properties of n-p System. H. G. KOLSKY, *Los Alamos Scientific Laboratory,* AND A. KLEIN, *Harvard University.**—The fourth-order potential of the pseudoscalar theory with pseudoscalar coupling has been computed to relative order $(\mu/M)^2$ compared to the leading two-pair term of order $(g^2/4\pi)^2(\mu/2M)^2$. Since the two-pair and one-pair terms effectively cancel, it is impossible to fit the low energy data with the potential computed to relative order (μ/M) only.

using the Lévy model. The contributions to the $(\mu/M)^2$ potential are provided by the no-pair terms, which yield a result equivalent to that of the ps-pv theory, as well as corrections to the two-pair and one-pair terms. To this order there are also velocity-dependent contributions which must be included in a consistent calculation. The static part of the second plus fourth-order potential is qualitatively similar, except for the central force in triplet odd states, to the potential of the ps-pv theory.[1] The damping of pair terms resulting from radiative corrections will not then qualitatively alter the low energy picture to the order considered, although it may be decisive in determining whether the theory has a meaning. Numerical results will be presented.

* Junior Fellow, Society of Fellows.
[1] Taketani, Machida, and Numa, Prog. Theoret. Phys. **I**, 45 (1952).

JA6. Convergence of Higher Order Adiabatic Potentials. ABRAHAM KLEIN,* *Harvard University.*—One of the criteria for the success of the Lévy model of nuclear forces is the rapid convergence of higher order potentials outside a cut-off radius $x_C=\mu r_C\sim 0.5$. We have therefore examined the leading terms of order $4n$ of the adiabatic potential for the ps-ps theory. For $n=1$, these are the so-called two-pair and one-pair terms already given.[1] The eighth-order analogs of these terms were also obtained directly by our adaptation of Lévy's method. The "leading" term of order $4n$ ($2n$ pairs), derived by a special technique, is given by

$$(-3)\mu(g^2/4\pi)^{2n}(\mu/2M)^{4n}n!(n-1)!(2/\pi)(K_1(2nx)/x^{2n}).$$

For moderate n, these terms increase rapidly with n for $x\sim 1$. It can also be inferred that the potential of relative order μ/M increases even more rapidly with n; in fourth-order it already effectively nullifies the two-pair potential, and for all higher orders it predominates. One is thus confronted with the double failure of the power series in $g^2/4\pi$ and of the series in μ/M for a given power of $g^2/4\pi$. One can only hope that radiative corrections will severely damp the higher order potentials.

* Junior Fellow, Society of Fellows.
[1] A. Klein, Phys. Rev. **89**, 1158 (1953).

JA7. Many-Body Forces and Nuclear Saturation. S. D. DRELL, K. HUANG, AND V. F. WEISSKOPF, *M.I.T.*—Nuclear saturation is studied with many-body interaction potentials derived from pseudoscalar meson theory. Lévy's two-body analysis[1] determines all parameters appearing in this calculation. The leading term in the n body potential depends only on the interparticle distances and is repulsive (attractive) for n odd (even).[2] The energy of the nucleus is calculated in the Hartree approximation with potentials up through five-body interactions and with neglect of Coulomb and surface effects. Saturation properties derived from these considerations are in accord with experience. Antisymmetrization of the nuclear wave function reduces the many-body interaction energies considerably by inhibiting the close approach of many particles. Thus the Pauli exchange terms are found to reduce the five-body interaction energy by 75 percent and to give a rapid convergence for the expansion in n body forces.

[1] M. M. Lévy, Phys. Rev. **88**, 275 (1952). We use only the leading terms of order $(G^2/4\pi)(\mu/2M)^2$ and $(G^2/4\pi)^2(\mu/2M)^2$. We believe Lévy to be in error in his calculation of terms of order $(G^2/4\pi)^2(\mu/2M)^3$ which we find to be repulsive and sufficiently large to alter his conclusions qualitatively.
[2] Wentzel's pair theory calculation [Helv. Phys. Acta **15**, 111 (1942)] reduces to these potentials in the perturbation limit.

JA8. Saturation of Nuclear Forces. ROBERT JASTROW, *Institute for Advanced Study.*—A variational calculation of the nuclear binding energy has been carried out using a hard sphere model of the nucleon in which the surrounding potential is taken as the fourth-order term in the symmetrical pseudoscalar theory with pseudoscalar coupling,[1,2] plus the three-body pair potential from the same theory. Correlations in the positions of the nucleons are included in the trial wave function and play an important role because of the highly singular and short-ranged character of the forces. The resultant many-body integrals resemble those occurring in the classical theory of the imperfect gas and are evaluated by the analog of an Ursell-Mayer development in powers of the density. A minimum occurs in the binding energy at a mean internucleon spacing of 1.1×10^{-13} cm, or 16 times the observed nuclear density.

[1] M. M. Lévy, Phys. Rev. **87**, 806 (1952); **88**, 725 (1952).
[2] R. Jastrow, Phys. Rev. **87**, 209 (1952).

JA9. The Damping of Virtual Nucleon-Pair Formation in Pseudoscalar Meson Theory.* K. A. BRUECKNER, *Indiana University*, AND M. GELL-MANN AND M. L. GOLDBERGER, *University of Chicago.*—The modifications of the propagation characteristics of a nucleon which result from the presence of a strongly coupled mesonic self field are estimated from the consideration of a simple subset of radiative corrections to the nucleon propagation function. It is found that reactive effects markedly inhibit nucleon pair formation so that the contributions from the pseudoscalar coupling term which do not involve nucelon pairs are strongly enhanced relative to those involving pair formation. In addition the meson pair coupling term, which results from nonrelativistic approximations to the relativistic linear coupling term and is intimately connected with nucleon pair formation, is strongly damped. The relation of this result to the nonrelativistic theory of Wentzel will be discussed.

* Supported in part by a grant from the National Science Foundation.

JA10. Nuclear Forces in the Pseudoscalar Meson Theory.* K. M. WATSON AND K. A. BRUECKNER, *Indiana University.*—The nuclear forces with pseudoscalar coupling have been evaluated approximately taking into account the scattering of the virtual mesons which give rise to the usual second and fourth order potentials. The solution of the multiple scattering equations shows that scattering off the energy shell is sufficiently weak to give only small effects for $\gamma>(\hbar/2\mu c)$. The formation of nucleon pairs has been taken into account using the estimate of the radiative effects given by one of us.[1] This tends to reduce the strength of the contribution to the potential which is associated with the formation of one and two nucleon pairs—a contribution which is weak for $\gamma>(\hbar/\mu c)$ and repulsive for γ somewhat less than $(\hbar/\mu c)$. The remaining potential gives for even states a strong attractive singlet force, a weak triplet force, and a strong tensor force of the correct sign. The odd states are dominated by a repulsive singlet force. Calculations of the low energy scattering parameters are in progress and will be discussed.

* Supported in part by a grant from the National Science Foundation.
[1] Brueckner, Gell-Mann, and Goldbergh (preceding abstract).

JA11. On the Tomonaga Approximation. B. D. FRIED AND R. J. RIDDELL, JR., *University of California, Berkeley.*—Tomonaga[1] has suggested an approximate method for treating the interaction of mesons with static nucleons which agrees with perturbation theory when g is small and with strong coupling theory when g is large. In this formalism, the Hamiltonian is split into two terms, $H=H_0+H_1$, where H_0 consists of all terms which contain only creation and destruction operators referring to a single meson configuration state $\phi_0(x)$. If it is assumed that only the configuration $\phi_0(x)$ is occupied in the ground state of the system, the function $\phi_0(x)$ can be determined by a straightforward variational procedure. Numerical calculations of the eigenvalues and eigenvectors of the Tomonaga Hamiltonian H_0 have been carried out for the ground state and several excited states in charged scalar, neutral pseudoscalar, and charged pseudoscalar meson theories with several values of coupling constant. This information can be used to compute quantities of physical interest

such as nucleon magnetic moments and meson-nucleon scattering cross sections. An estimate of the validity of the formalism is obtained by treating H_1 as a perturbation on H_0 and investigating, for example, its effect upon the ground state energy.

[1] S. Tomonaga, Prog. Theoret. Phys. **2**, 6 (1947).

JA12. On the Number of Feynman Diagrams. R. J. RIDDELL, JR, *University of California, Berkeley.*—The total number of Feynman diagrams for a given type of interaction Hamiltonian may be obtained in general by a very simple analysis. In quantum electrodynamics, it will be shown to be

$$\frac{(n!)^2}{(\epsilon!)^2(n-\epsilon)!}\cdot\frac{n!}{\rho!(n-\rho/2)!2^{n-\rho/2}},$$

in which the first factor corresponds to the number of different diagrams using only electron lines, and the second is due to the photon diagrams. n is the order of the perturbation; ϵ, ρ are the number of free electron and photon lines, respectively.[1] The removal of unwanted diagrams may readily be accomplished through the use of generating functions. Relations which these functions satisfy will be exhibited. From these, the desired numbers of diagrams may easily be obtained for not too large n. Using these relations it can be shown that the asymptotic dependence of the number of diagrams on n is not markedly affected by such removals, and the number of diagrams is of order $\exp\{\frac{3}{2}n\log n\}$.

[1] This result has also been obtained by C. A. Hurst [Proc. Roy. Soc. (London) **A214**, 44 (1952)].

JA13. Properties of the Salpeter-Bethe Two-Nucleon Equation. JACK S. GOLDSTEIN, *Institute for Advanced Study.*—The relativistic two-nucleon equation of Salpeter and Bethe[1] is examined in the ladder approximation for large binding energy, with an invariant interaction function. The binding energy is considered an adjustable parameter and the coupling constant λ is taken as the eigenvalue of the problem. As a starting point for this study, the special case of two equal masses and binding energy equal to the total mass is considered. It is found that in this case the equation may be simplified to a remarkable degree. For zero quantum mass, a one-dimensional integral equation in momentum space is obtained, and solved, in closed form. The solutions can also be displayed in closed form in configuration space. Solutions exist corresponding to this binding energy for all positive λ. Requiring normalizability on a space-like surface in configuration space eliminates solutions for sufficiently small λ, but a normalizable continuum remains. It is shown that by introducing a high frequency cutoff into the particle propagators and then going to the limit of infinite cutoff, the remaining continuum is reduced to a single physically sensible solution.

[1] E. E. Salpeter and H. A. Bethe, Phys. Rev. **84**, 1232 (1951).

JA14. Compton Scattering on Nucleons. R. H. HUDDLESTONE, *University of California, Berkeley.*—A classical calculation has been carried out to determine the effect of nucleon structure upon scattering of photons. This structure is provided by a pseudoscalar field with gradient coupling to an extended source of size a $\mu\sim0.5$, chosen to give semiquantitative agreement with the virtual isobaric level suggested by high energy meson-nucleon scattering and other meson processes. The nucleon is coupled directly to the electromagnetic field by means of a Pauli magnetic moment term. It is found that the meson coupling provides a resonance near $\omega/\mu=2$ for coupling constant $f^2/4\pi=0.3$. The peak value of the total cross section is $\sigma_{max}\sim5g^4\times10^{-31}$ cm^2, where g is the gyromagnetic ratio of the nucleon. This value is approximately $1.5\sigma_m$, where σ_m corresponds to a bare magnetic dipole. The angular distribution varies from $(1-\frac{1}{3}\cos^2\theta)$ at $\omega/\mu=1$ to $(1+\frac{1}{3}\cos^2\theta)$ at $\omega/\mu=3$. These results are given for a neutral meson field. The symmetric theory is under investigation and results will be reported at the meeting.

FRIDAY MORNING AT 9:45

NBS, East Building

(CONYERS HERRING presiding)

Invited Papers in Solid-State Physics

K1. Semiconducting Intermetallic Compounds. R. G. BRECKENRIDGE, *National Bureau of Standards.* (30 min.)

K2. Dislocations in Low Angle Crystal Boundaries. F. L. VOGEL, *Bell Telephone Laboratories.* (30 min.)

K3. Trivalent Substitutions in the Ferrites. L. R. MAXWELL, *Naval Ordnance Laboratory.* (30 min.)

K4. Electromagnetic Phenomena in Ferrites. C. L. HOGAN, *Bell Telephone Laboratories.* (30 min.)

FRIDAY MORNING AT 9:30

Shoreham, West Ballroom

(W. W. BUECHNER presiding)

Reactions of Transmutation and Inelastic Scattering, I.

KA1. The Photodisintegration of the Deuteron at 20 Mev. E. V. WEINSTOCK AND J. HALPERN, *University of Pennsylvania.*—Using ZnS detectors previously employed for measuring photoproton angular distributions in other elements,[1] we have measured the angular distribution in the deuteron photodisintegration produced by bremsstrahlung photons between 18

and 22 Mev. A 25 mg/cm² deuterated paraffin target was irradiated using the Pennsylvania betatron run at 22 Mev. Appropriate foils between target and detectors removed all photoprotons produced by photons below 18 Mev. Thus all carbon photoprotons from the target were also removed. The betatron output was monitored by direct counting of the neutrons from the (γ, n) reaction in tantalum. After applying a target absorption correction amounting to a maximum of 3 percent and converting the angular distribution to the center-of-mass system, the measured distribution from 5000 preliminary events had the expected form, $a+\sin^2\theta(1+2\beta\cos\theta)$, with $a=0.19\pm0.07$, and $\beta=0.1$. The total cross section was found to have the value 5.5×10^{-28} cm², with an error limited by the knowledge of the number of photons in the bremsstrahlung. A 20 percent probable error is estimated. Comparison will be made with other experimental results and with theory.

[1] Mann, Halpern, and Rothman, Phys. Rev. **87**, 146 (1952).

KA2. The H³+He³ Reactions. C. D. MOAK, *Oak Ridge National Laboratory.*—The reactions which occur when tritium is bombarded by He³ were first observed by Almqvist, Allen, Dewan, and Pepper, using an unresolved twenty microampere ion beam of 200 kev energy containing 10 percent He³ ions.[1] The reactions are as follows:

$$H^3+He^3\rightarrow Li^{6*}\rightarrow He^4+H^2+14.31\text{ Mev} \quad (1)$$
$$\rightarrow He^4+H^1+n^1+12.08\text{ Mev} \quad (2)$$
$$\rightarrow He^{5*}+H^1+Q. \quad (3)$$

Using vacuum-mounted NaI crystals as detectors and using the He³ ion beam from the 400 kev Cockcroft-Walton accelerator, the charged particle spectrum for reactions (1), (2), and (3) has been obtained and will be presented. The cross sections of reactions (1), (2), and (3) have been measured and the data will be presented. From the spectrum data a value of 0.95 ± 0.07 Mev has been measured for the breakup of He⁵ in its ground state into an α particle and a proton.

[1] Almqvist, Allen, Dewan and Pepper, Phys. Rev. **83**, 202 (1951).

KA3. Cross Section of $He^3(H^2, H^1)He^4$ Reaction from 100–800 kev He³ Energy. W. E. KUNZ, *Oak Ridge National Laboratory.*—The He³ beam from a 400 kilovolt Cockcroft-Walton type accelerator was used to study the reaction $He^3(H^2, H^1)He^4$. The angular distribution of the protons from a thick deuterium target was determined at bombarding energies of 200, 290, and 360 kev and found to be isotropic. The differential cross section at 90° was determined by alternately bombarding a deuterium target with H³ and He³ and counting the alpha-particles from the $H^3(H^2, n)He^4$ and $He^3(H^2, H^1)He^4$ reactions. The known $H^3(H^2, n)He^4$ cross section gave the absolute value of the $He^3(H^2, n)He^4$ cross section which has a peak of 0.72 barn at 640 kev He³ energy. The range 400–800 kev was covered by using doubly ionized He³ produced by a rf type ion source.

KA4. The He³+He³ Reaction. W. M. GOOD, W. E. KUNZ, AND C. D. MOAK, *Oak Ridge National Laboratory.*—A He³ target was made by bombarding an aluminum foil with a 30μa beam of He³ ions at 84 kev. The number of He³ atoms in the target was determined by bombarding the target with a beam of deuterons and observing the rate of the $d(He^3, He^4)p$ reaction, whose cross section is known. The He³+He³ cross section *versus* bombarding energy was obtained, and this cross section showed an energy dependence rising somewhat more steeply than Gamow penetrability over the range 100 kev to 800 kev. At a bombarding energy of 800 kev, but a He³ energy uncertain by target thickness, the cross section is about 4 millibarns. The spectrum of protons from the breakup of Be⁸ was obtained by means of a NaI crystal spectrometer. About 10 percent of the Be⁸ disintegrations go to Li⁸+H¹ and 90 percent go to He⁴+H¹+H¹.

KA5. He³ Reactions in Cu and Si. M. L. POOL AND D. N. KUNDU, *Ohio State University.*—Helium gas enriched to 50 percent in its He³ content was used in a cyclotron to provide 13 Mev He³ particles. A recirculation system allowed continuous bombardments of targets for prolonged periods with only a few cc of the gas. The following He³ reactions were identified from the disintegration characteristics of the radioactive nuclides produced from Cu: $Cu^{63}(He^3, \alpha)Cu^{62}$ (10.1 min), $Cu^{65}(He^3, \alpha)Cu^{64}$ (12.9 hr), $Cu^{63}(He^3, n)Ga^{65}$ (15 min), $Cu^{65}(He^3, n)Ga^{67}$ (3.24 days), and $Cu^{65}(He^3, 2n)Ga^{66}$ (9.5 hr). The 250-day Zn^{65} produced with a large yield may arise through a combination of the reactions $Cu^{63}(He^3, p)$, $Cu^{65}(He^3, H^3)$, and $Cu^{63}(He^3, n)Ga^{65}\rightarrow Zn^{65}$. The relative cross sections observed are approximately $\sigma_{62}(He^3, \alpha):\sigma_{65}(He^3, \alpha):\sigma_{63}(He^3, n):\sigma_{65}(He^3, n):\sigma_{65}(He^3, 2n)=3:1:22:2:1$. A silicon target yielded activities ascribable to the reactions $Si^{30}(He^3, p)P^{32}$ (14.3 days), $Si^{30}(He^3, 2p)Si^{31}$, $Si^{28}(He^3, p)P^{30}$, and/or $Si^{28}(He^3, n)Si^{30}\rightarrow P^{30}$ (2.55 min). Spurious neutron activation was excluded through suitable monitoring.

KA6. $Li^6(n, \alpha)H^3$ Cross Section as a Function of Neutron Energy.* F. L. RIBE, *Los Alamos Scientific Laboratory.*—Earlier absolute measurements[1] of the $Li^6(n, \alpha)H^3$ cross section have been extended and now cover the range of neutron energies from 0.88 to 14.2 Mev. The errors of the measurements vary from 11 to 18 percent. At its low energy end, the curve $\sigma(E_n)$ joins smoothly with an extension of the earlier data of Blair and Holland,[2] for which the maximum neutron energy was 0.62 Mev. A log-log plot of $\sigma(E_n)$ for the present data shows a variation approximately as E_n^{-1} for the high energy portion of the curve with a break to greater flatness at the lower energies, resulting in a broad hump in the cross-section curve at about 2 Mev. We intend to estend the measurements to lower neutron energies and further to improve their accuracy.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] F. L. Ribe, Phys. Rev. **87**, 205 (1952).
[2] J. M. Blair and R. E. Holland, quoted in D. J. Hughes, *et al.*, AECU 2040 (1952).

KA7. Absolute Magnetic Analysis of the Reaction Energies of $Li^6(d, \alpha)He^4$, $Li^7(p, \alpha)He^4$, and $C^{13}(d, \alpha)B^{11}$.* G. C. PHILLIPS, K. F. FAMULARO,† AND C. R. GOSSETT, *Rice Institute.*—The Rice Institute charged particle spectrometer has been used to analyze the ground state alpha-particles from the nuclear reactions listed above. The Q values obtained for the targets were Li^6, $22.375\pm.014$ Mev; Li^7, 17.344 ± 0.013 Mev; C^{13}, 5.116 ± 0.005 Mev. The stabilization of the bombarding energy, the spectrometer line shapes, and the sources of error will be discussed. The results of the measurements will be compared to similar measurements in other laboratories.

* Supported by the U. S. Atomic Energy Commission.
† Now at the University of Minnesota, Department of Physics.

KA8. The $Li^6(d, t)Li^5(p)He^4$ Reaction.* R. T. FROST AND S. S. HANNA, *The Johns Hopkins University.*—The $Li^6(d, t)Li^5(p)He^4$ reaction, reported earlier,[1] has been investigated at a bombarding energy of 1.0 Mev. In order to minimize carbon and oxygen groups occurring in the interesting region, heated Li^6Cl targets were used. The reaction products were examined by magnetic analysis through an energy range of $0.7-2.0$ Mev for tritons and $0.8-6.0$ Mev for protons. A broad triton group was observed with the correct shape and energy to be identified with the transition to the ground state of Li⁵. The observed structure gives a $Q=0.9\pm0.1$ Mev and a width of 1.5 Mev for the Li⁵ ground state. A continuous proton distribution was also observed with a sharp upper limit at 2.80 Mev. This limit and the general shape of the continuum agree well with the distribution expected for protons emitted from recoiling, disintegrating Li⁵ nuclei. The upper limit gives $Q=2.51\pm0.04$ Mev for the three-particle disintegration, and hence a $Q=1.6$ Mev for the $Li^5(p)He^4$ process. The actual shape of the proton

continuum is a fairly sensitive function of directional correlations among the particles. Preliminary calculations, aided by an IBM calculator, indicate that the major observed effect may be attributed to a pronounced forward distribution of the tritons.

* Aided by a contract with the U. S. Atomic Energy Commission.
[1] R. W. Gelinas and S. S. Hanna, Phys. Rev. **86**, 253 (1952).

KA9. Capture Gamma-Rays from the Proton Bombardment of Beryllium. W. F. HORNYAK AND T. COOR, *Brookhaven National Laboratory.**—The gamma-rays produced at the 0.998 and 1.087 Mev proton capture resonances in Be^9 (corresponding to levels in B^{10} at 7.48 and 7.56-Mev, respectively) were studied using a NaI scintillation spectrometer. Gamma-ray lines corresponding to energies of 0.41, 0.71, 1.02, 1.4, and 7.5-Mev are clearly resolved at the 0.998-Mev resonance. There are indications of additional lines between 1.4 and 7.5-Mev. The radiation at the 1.087-Mev resonance has energies of 0.71, 1.4, ~2, and 6.8-Mev. The absence of the 1.02-Mev gamma-ray as well as the apparent absence of the direct transition to the ground state at the 1.087-Mev resonance is consistent with a spin assignment of $J=0$ to this level. An absolute efficiency calibration of the NaI crystal permitted the determination of the absolute yield of the various gamma-rays observed. Thick target (beryllium metal) yield for the 0.71 and 1.02 Mev gamma-rays and a thin target (evaporated beryllium metal) yield for the 0.71 Mev gamma-ray have been obtained.

* Under the auspices of the U. S. Atomic Energy Commission.

KA10. Neutrons from the Proton Bombardment of Be^9.* F. AJZENBERG,† C. M. BRAAMS, AND W. W. BUECHNER, *M.I.T.*—A thin foil[1] of Be^9 mounted on a thick tantalum backing has been bombarded with 6.59-Mev protons from the MIT-ONR Van de Graaff generator. The resultant neutrons have been studied by means of Ilford C2 emulsions, 200 microns thick, mounted 10 centimeters from the target and at various angles to the incident beam. Preliminary measurements at 0, 90, and 135 degrees indicate a level at 2.36 ± 0.08 Mev in B^9 which is presumably the mirror level of the 2.429-Mev state[2] in Be^9. The peaks corresponding to the ground state and the 2.36-Mev level are superimposed on a continuous distribution of neutrons.[3]

* This work has been supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Also at Smith College.
[1] We are indebted to Dr. H. Bradner for this foil.
[2] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 321 (1952).
[3] Johnson, Ajzenberg, and Laubenstein, Phys. Rev. **79**, 187 (1950).

KA11. Neutrons from $Be^9(d, n)B^{10}$. J. S. PRUITT, S. S. HANNA, AND C. D. SWARTZ, *The Johns Hopkins University.*—Neutrons from the reaction $Be^9(d, n)B^{10}$ were produced by bombarding a thin beryllium target with 0.96-Mev deuterons. The energies and angular distributions of these neutrons were studied by observing recoil proton tracks in nuclear emulsions placed at six angles relative to the deuteron beam. Five groups of neutrons were found, corresponding to the production of B^{10} in its ground state and first four excited states. The angular distributions for the ground state and first excited state were interpreted on the basis of compound nucleus formation; those for the other three excited states were interpreted as showing both compound nucleus formation and deuteron stripping, with the stripped proton captured in a p orbit in each case. With the help of rules concerning the complexity of the compound nucleus distributions, it has been possible to conclude that the second excited state of B^{10} has spin 0, and that each of the other three excited states has a spin of either 1 or 2. As a by-product of this investigation, evidence was found for the presence in the compound nucleus B^{11} of two states with excitation energies of about 16.7 Mev, and with spins and parities of $\frac{3}{2}^+$ and $\frac{5}{2}^-$.

KA12. (d, t) Reactions and the Triton "Wave" Function.* D. R. BACH AND P. V. C. HOUGH, *University of Michigan.*—The work of El-Bedewi[1] on the angular distributions of tritons from the reaction $Be^9(d, t)Be^8$ at 7.7-Mev deuteron energy has been extended to smaller and larger angles. In agreement with the results of El-Bedewi and Fulbright *et al.*,[2] the first zero predicted by Butler and Salpeter[3] appears experimentally as a minimum followed by a slight second maximum. The experimental distribution will be compared with theoretical curves calculated under various assumptions for the triton wave function. Work on the analogous reaction in C^{13} is in progress.

* Supported in part by the U. S. Atomic Energy Commission.
[1] F. A. El-Bedewi, Proc. Phys. Soc. (London) **64**, 947 (1951).
[2] Fulbright, Bruner, Bromley, and Goldman, Phys. Rev. **88**, 700 (1952).
[3] S. T. Butler and E. E. Salpeter, Phys. Rev. **88**, 133 (1952).

KA13. Energy Levels of B^{11} and B^{12} by (d, p) Reaction.* M. M. ELKIND† AND A. SPERDUTO, *M.I.T.*—Evaporated targets of metallic natural boron and enriched B^{10} deposited on formvar films were bombarded with deuterons produced by the MIT-ONR accelerator. Incident energies from 4.25 to 8.52 Mev were used. Proton groups emitted at 90° to the deutron beam were analyzed with a 180° magnetic spectrograph. The studies have covered a region of excitation from 7.50 to 11.46 Mev in B^{11}, and from zero to 3.40 Mev in B^{12}. In the case of B^{11} a level at 7.99 Mev has thus far been found in addition to those previously reported.[1] In B^{12}, proton groups have been observed corresponding to the ground state and levels at 0.95, 1.67, 2.62, 2.72, and 3.38 Mev of which only the first two groups were previously reported by (d, p) reaction.[1] The B^{12} level at 1.67 Mev has been observed by $Be^9(\alpha, p)B^{12}$, although the last three levels were not reported by this reaction.

* This work has been supported by a joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.
† From the Laboratory of Biophysics, National Cancer Institute, National Institutes of Health, Bethesda, Maryland.
[1] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 321 (1952).

KA14. The Yield of α-particles from the Reaction $B^{11}(p, \alpha)Be^8$. E. B. PAUL AND R. L. CLARKE, *Chalk River Laboratories.*—The yield of the long range (α_0) and short range (α_1) alpha-particle groups from this reaction have been studied at 90° to the proton beam for proton energies between 0.4 and 2.8 Mev. The proton beam from the Chalk River electrostatic accelerator bombarded an evaporated boron target about 20 kev thick. The α-particles were analyzed magnetically and detected in a proportional counter. The following resonances were observed (relative maximum yields due to each resonance are shown):

E_p	Γ in kev	Y_{max} for α_0	Y_{max} for α_1
0.68	250	<0.04	35.4
1.4	1200	1.0	8.8
2.0	150	1.4	2.3
2.65	300	2.6	10.5

Preliminary determinations of the angular distribution of α_0 at 1.4 Mev and of α_1 at 0.7 Mev indicate 2+ and 2− for the corresponding C^{12} states. The relative weakness of the α_1 group at the 2.0 Mev resonance suggests 0+ for the corresponding level.

KA15. The Yield and Angular Distribution of Gamma-Rays from $B^{11}(p\gamma)C^{12}$. H. E. GOVE AND E. B. PAUL, *Chalk River Laboratories.*—The yield of 12 and 16 Mev gamma-rays from this reaction has been measured at 90° for proton energies between 0.6 and 2.8 Mev. The 12 Mev gamma-ray was resonant at 0.7, 1.4, 2.0, and 2.6 Mev and the 16 Mev at 1.4 and 2.6 Mev. The results at 0.7 and 1.4 agree with Huus and Day.[1] Angular distributions of the two gamma-rays have been measured at nine energies in the range investigated. The Legendre

coefficients near resonance are

	γ_0(16 Mev)		γ_1(12 Mev)	
E_p	a_1/a_0	a_2/a_0	a_1/a_0	a_2/a_0
0.7			0.08	0.05
1.4	−0.01	0.23	0.36	0.08
2.0			0.33	0.45
2.6	0.08	−0.43	0	−0.15

The following tentative conclusions can be drawn. The two lower states are of opposite parity. If the 1.4 Mev state is 2+ (as indicated by the $B^{11}(p\alpha)Be^8$ results), then the 0.7 Mev state is 2− and these are consistent with the above distributions. The 2.6 Mev state is 2+.

[1] Huus and Day (private communication).

FRIDAY MORNING AT 9:30

Wardman Park, Continental Room

(J. E. MAYER presiding)

Business Session of the Division of Chemical Physics
Molecular and Chemical Physics

L1. Stark Effect in High Temperature Microwave Spectroscopy.* P. TATE AND M. W. P. STRANDBERG, *M.I.T.*—A simple high temperature microwave spectrograph has been built. Four rotational transitions in $K^{39}Cl^{35}$ and two in $K^{39}Cl^{37}$ have been observed. Those in $K^{39}Cl^{35}$ agree with the same transitions observed by Stitch, Honig, and Townes.[1] Rotational constants agree within experimental error with those found by molecular beam methods.[2] The Stark patterns for the transitions $J=2\rightarrow3$, $v=0$ in $K^{39}Cl^{35}$ and $J=1\rightarrow2$, $v=0$ in $Na^{23}Cl^{35}$ have been studied. From these the electric dipole moments of $K^{39}Cl^{35}$ and $Na^{23}Cl^{35}$ have been determined.

* This work was supported in part by the U. S. Signal Corps, the Air Materiel Command and the U. S. Office of Naval Research.
[1] Stitch, Honig, and Townes, Phys. Rev. **86**, 607 (1952).
[2] Fabricand, Carlson, Lee, and Rabi, Phys. Rev. **86**, 607A (1952).

L2. The Rotational Spectrum and Molecular Structure of Methyl Mercaptan.* N. SOLIMENE AND B. P. DAILEY, *Columbia University.*—The $J=0\rightarrow J=1$ transitions of several of the isotopic species of methyl mercaptan have been studied.

Species \ $J=0\rightarrow J=1$	Ground vibrational state	First excited torsional state	Second excited torsional state	Calculated ground state
CH_3SH	25291.8 mc	25219.7 mc	25132.4 mc	25292 ±5 mc
	25290.8	25206.8	25126.9	
$C^{13}H_3SH$	24388.0	24318.5	24256.2	24384 ±5
	24387.1	24306.2	24245.0	
CH_3SD	24387.5	24321.6		24385 ±5
	24385.0	24301.6		
CD_3SH	20732.8	20678.9	20627.6	20728 ±5
	20732.0	20674.8	20619.0	
$CH_3S^{34}H$	24879.1			24881 ±5

The following structural parameters were determined from the frequencies of the unresolved ground state lines assuming $d_{CH}=1.100$A,[3] $\angle HCH=110°13'$[2] and a staggered configuration =

$$d_{SH}=1.345\text{A}, \quad d_{CS}=1.808\text{A}, \quad \angle CSH=99°26'.$$

[1] Assisted by the U. S. Signal Corps and the Research Corporation of New York.
[2] Miller, Aamodt, Dousmanis, Townes, and Kraitchman, J. Chem. Phys. **20**, 1112 (1952).

L3. The Vibrational Spectra of $F_2C{:}CF_2$ and $Cl_2C{:}CCl_2$.* D. E. MANN, N. ACQUISTA, AND EARLE K. PLYLER, *National Bureau of Standards.*—The infrared spectra of gaseous $F_2C{:}CF_2$ and liquid $Cl_2C{:}CCl_2$ in the region 270–190 cm^{-1} have been measured for the first time. The spectrum of the latter above 270 cm^{-1} has been reinvestigated. The b_{2u} fundamentals p-CF_2 and p-CCl_2 have been observed directly. There is some evidence to show that the torsion fundamental of $F_2C{:}CF_2$ appears in the infrared spectrum as a result of a Coriolis interaction with the b_{2u} vibration. These data together with the recently determined value for the entropy of $F_2C{:}CF_2$ have permitted the earlier assignments[1,2] to be refined.

* Supported in part by the U. S. Office of Naval Research.
[1] Nielsen, Claassen, and Smith, J. Chem. Phys. **18**, 812 (1950).
[2] H. J. Bernstein, J. Chem. Phys. **18**, 478 (1950).

L4. Theory of the Rotational Spectra of Allene Type Molecules.* M. MIZUSHIMA, *Duke University.*—It was pointed out by the present author and Venkateswarlu[1] that pure rotational spectra is possible to be observed in allene type molecules, if it is in a vibrationally excited state. The nuclear spin has an interesting effect on this kind of spectra. The statistical weight of each rotational and rovibrational state is calculated for arbitrary spin value. It is pointed out that the nuclear spin has an effect on the matrix element of dipole moment itself in our spectra. Thus the intensity will be a complicated function of nuclear spin. In the case of Zeeman effect and Stark effect some transitions will be completely prohibited through nuclear spin. The fine structure due to inversion and internal rotation is estimated to be extremely small. The number of lines due to hyperfine structure is calculated by group theoretical method.

* The research reported in this paper has been sponsored by the Geophysics Research Directorate of Air Force Cambridge Research Center.
[1] M. Mizushima and P. Venkateswarlu (to be published).

L5. Configurational Interaction in Molecular Orbital Theory and the Relative Energies of Polar and Nonpolar Functions.* MAX WOLFSBERG, *Brookhaven National Laboratory* (introduced by Norman Elliott).—The introduction of configurational interactional interaction into the molecular orbital theory treatment has, in most homonuclear molecules, the effect of increasing the contribution of nonpolar functions with respect to polar functions. This increase is largely due to the fact that nonpolar functions are calculated to have much lower energies than polar functions. At infinite separation of the nuclei, one usually finds that the computed energy difference between polar and nonpolar functions is larger than the experimental one. The question[1] then arises whether one calculates these differences correctly at shorter internuclear separations. The effect of decreasing the energy differences between polar and nonpolar functions will be discussed. These matters will be illustrated by actual computations on some molecules.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.
[1] This was originally pointed out by W. Moffit, Proc. Roy. Soc. (London) **A210**, 224 (1951).

L6. Matrix Formulation of Molecular Orbital, Heitler-London, and Configurational Interaction Computations. PAUL F. WACKER, *Catholic University of America.*—A direct product matrix and an ordinary matrix may express all integrals necessary for Hartree-Fock molecular orbital (MO), Heitler-London (HL), and configurational interaction (CI) treatments. Use of symmetry and operator properties is conveniently made. All necessary formulas have been derived for a variation treatment in each of the three methods. Let $\mathbf{Y}$ and $\mathbf{Z}$ be row vectors with standard and molecular spin orbitals, respectively, as elements, $\mathbf{Z}=\mathbf{YC}$, $\mathbf{H}=\int \mathbf{Y}^{*u} H'^{uv} \mathbf{Y}^{u} dv^{u}$, and $\mathbf{j}=\int (\mathbf{Y}^{*u}\times\mathbf{Y}^{*v}) H'^{uv} (\mathbf{Y}^{u}\times\mathbf{Y}^{v}) dv^{uv}$, where a superscript designates an electron, $*$ is the Hermitian operator, $\times$ is the direct product operator, $\mathbf{C}$ is a constant matrix, and H'^{u} and H'^{uv} act only upon the electrons indicated. For the MO method or a single configuration in the CI method, the eigenvalue $M=tr(\mathbf{H}+\{tr_{2,4}(\mathbf{h}-\mathbf{h}^{T_{2,4}})_{2,4}\boldsymbol{\varrho}\}\boldsymbol{\varrho})$, where $\boldsymbol{\varrho}=\mathbf{CC}^{*}$, $T_{2,4}$ interchanges columns and subcolumns, the subscripts 2,4 on the matrices cause $\boldsymbol{\varrho}$ to operate on each submatrix, and $tr_{2,4}$ takes the trace of each submatrix. The same equation applies for the HL method if $\boldsymbol{\varrho}$ is a unit matrix except for zero diagonal elements corresponding to orbitals missing from the configuration.

L7. Thermodynamic Activities in Iron-Nickel Alloys. R. A. ORIANI (introduced by B. H. Zimm).—The activity of Fe in iron-nickel alloys was studied in a differential apparatus by equilibrating mixtures of H_2O/H_2 gases over pure iron and over the alloys. Errors caused by thermal diffusion are minimized in this design, and the measured activity of iron is corrected for the variation of the activity of wüstite with ambient gas composition. Formation of magnetite prevents the investigation of nickel-rich alloys. In the iron-rich fcc alloys the solid solution is very nearly ideal; the activity coefficients are generally only slightly smaller than unity, the entropies of mixing are slightly larger than the ideal values, and the heats of mixing are small positive numbers.

L8. Mass Spectrometric Study of the Sublimation of Graphite. RICHARD E. HONIG, *R.C.A. Laboratories.*—The emission of neutral and charged carbon molecules from spectroscopically pure graphite has been studied in a 180° mass spectrometer. Small filaments (diameter: 0.014 inch) were heated by ac up to 2600°K and gave off neutral species which, upon bombardment by 70-volt electrons, yielded the following positive ion spectrum: $C_3^+=100$; $C_2^+=13$; $C_1^+=35$. While the effects of fragmentation and of differences in ionization cross sections may not be negligible, it is believed that carbon vapor largely consists of C_3 molecules. With the electron beam off, negative ions containing from one to eight carbon atoms were observed. C_2^-, C_4^-, and C_3^- were the most abundant species, in that order. The concentration ratio C_3^-/C_2 was about 0.002. No emission of positive carbon ions could be detected. Heats of sublimation were measured for the neutrals and the more abundant negative ions, and electron affinities were computed. $L(C_3)=168\pm10$ and $L(C_2)=190\pm20$ kcal/mole, while $L(C_1)$ awaits confirmation. It will be shown that these results, which agree partially with a recent parallel study,[1] can account for the inconsistencies existing in the voluminous literature on this subject.

[1] W. A. Chupka and M. G. Inghram, J. Chem. Phys. **21**, 371 (1953).

L9. Vapor-Liquid Transitions in a Closed System.* CHARLES WILLIS AND HARRY L. FRISCH, *Syracuse University.*—A formal nonlinear kinetic scheme for the formation of subcritical nuclei of a liquid from a supersaturated vapor in a closed system was formulated without the assumption that the actual distribution does not depart appreciably from a canonical distribution. The average number of subcritical nuclei as a function of size and time is presented as a power series in a parameter ϵ which is the ratio of the average rate constant for accretion to the average decay constant. If the condition that the system be closed is relaxed and if all elementary steps involve either the accretion or loss of a single "vapor" molecule, then the equations governing the process reduce to the linear equations derived by Becker and Döring.[1] Comparisons between the linear and nonlinear equations of the two theories will be presented.

* Supported by Office of Scientific Research, USAF.
[1] R. Becker and W. Döring, Ann. Physik **24**, 719 (1935).

L10. On the Question of Molecular Rotation in Liquids. EDWARD J. BRENEMAN AND DUDLEY WILLIAMS, *The Ohio State University.*—Previous investigations of the infrared spectra of liquids have not produced unambiguous answers to the question of molecular rotation in liquids. In general, infrared absorption bands of liquids become narrower as the temperature is reduced, but the band contours are not similar to contours of corresponding absorption bands of the vapor. For "associated" liquids such as H_2O, NH_3, and CH_3OH this is to be expected in view of strong intermolecular forces; for certain other liquids the large molecular moments of inertia prevent the detection of rotational structures. Lack of rotational structure in the spectrum of HCl in various solvent has been attributed to "steric hindrance." Such "steric hindrance" is minimized when spherical-top molecules such as CH_4 are dissolved in a solvent consisting of spherical-top molecules, such as CCl_4. In the present work the band near 3000 cm^{-1} in the spectrum of CH_4 in CCl_4 was studied by means of a high dispersion spectrograph and was compared with the corresponding band in the spectrum of gaseous CH_4. There are evidences of P, Q, and R branches in the solute band which correspond to those appearing in gases at high pressure.

L11. Radiation Effects and the Rotational-Translational Relaxation Time Constant.* PHILIP M. MOSTOV AND SIDNEY BOROWITZ, *New York University.*—In a previous paper[1] the moment method[2] solution of the Boltzmann equation was generalized to the rough sphere molecule, and a system of 17 equations derived which are capable of treating phenomena in which the rotational and translational temperatures are different. The interpretation and evaluation of the so-called rotational-translational relaxation time constant may be obtained from the equation formed by taking the difference between the rotational and translational temperature equations, under appropriate simplifying assumptions. To account for the effects of possible radiations to and from molecules, radiation terms are incorporated in the two temperature equations. For periodic phenomena the type of behavior exhibited is found to depend in an important way upon the ratio of the time constant to the period of the radiation cycle. When the densities are so low that the mean collision time is comparable with the effective period of the radiation source, one could have differences between the rotational and translational temperatures for appreciable times.

* Assisted in part by the U. S. Office of Naval Research and the U. S. Air Force.
[1] Mostov, Grad, and Borowitz, Bull Am. Phys. Soc. **28**, No. 1, 47 (1953).
[2] H. Grad, Commun. Pure and Appl. Math. **2**, 331 (1949).

L12. Bose-Einstein Condensation of an Imperfect Gas. M. H. FRIEDMAN AND S. T. BUTLER, *Cornell University.*—The partition function for a system of particles obeying Bose-Einstein statistics has been computed assuming a strong repulsive interparticle interaction, with a range short compared to the mean wavelength λ. Under these conditions, it can be shown that the major quantum-mechanical effect, outside of the statistics, is to replace the $e^{-V/kT}$ of the classical gas by a function $e^{-f(1/kT)}$, where V is the total interaction and f is a function obtained from V and characterized by the same range. The statistics lead to an effective attractive

potential of range λ, as in the case of the perfect gas, but this is now partially offset by the repulsive effect of the function f. Thus we still obtain a Bose-Einstein condensation. However, this now occurs at a lower temperature than previously obobtained for the ideal gas at the same density. When V is taken to be the sum of the interactions between helium atoms (neglecting the weak, long range attractive part) and the density is taken to be that of liquid helium, we obtain a condensation temperature of about 2.2°K. The thermodynamic properties of this system are being investigated.

L13. A Mass Spectrometric Positive Ion Technique for Determining Phase Transition Temperatures and Heats of Transformation in Metals.* R. G. JOHNSON,† W. C. CALDWELL,† D. E. HUDSON, AND F. H. SPEDDING, *Iowa State College.*—A positive ion technique has been developed which permits the determination of solid to solid and solid to liquid phase transition temperatures and heats of phase transformation for several metals. The metal under study is placed in a high temperature tantalum crucible. The metal atoms effuse out through an orifice, strike a hot, clean tungsten filament and are re-evaporated. A fraction of the atoms evaporate as ions. These ions are analyzed and the corresponding current is measured with a conventional Nier type mass spectrometer. The effusion crucible conditions are those of the Knudsen method of vapor pressure determination. The ion beam current is measured as a function of crucible temperature from which data heats of transformation may be determined. Heat of vaporization measurements give 78.70±0.39 kilocalories per mole for aluminum at 1059°C, about 79.5 kilocalories per mole for praseodymium at 1050°C, and about 69.3 kilocalories per mole for neodymium at 1075°C. Melting point determinations using samples containing less than 0.1 percent of foreign metals give 919±2.5°C for praseodymium and 1019±2.5°C for neodymium. A solid to solid state transition is observed in neodymium at 869±2.5°C.

* Work performed under contract with the U. S. Atomic Energy Commission.
† Now with Bendix Aviation Corporation, Red Bank Division.

L14. The Compressions to 150 000 Pounds per Square Inch for a Series of High Molecular Weight Liquid Hydrocarbons. R. H. MCMICKLE,* R. W. SCHIESSLER, AND W. WEBB, *The Pennsylvania State College.*—The isothermal compressions have been measured for a series of structurally related liquid hydrocarbons with an essentially constant molecular weight near 350 g. The pressure range was atmospheric to 150 000 pounds per square inch, with six temperatures being chosen in the range 100°F to 275°F. With constant molecular weight and symmetry, it has been found that the compressions for the saturated hydrocarbons decreased very nearly linearly with increasing percent carbon atoms in rings. The isotherms have been fitted by two different equations of state, each of which had been applied previously by other workers, to liquids of lower molecular weight. Within certain limits of molecular symmetry, the compressions to 150 000 pounds per square inch for two binary liquid mixtures were found to equal the compressions of chemical compounds having the same molecular weight and average cyclic composition.

* Now at the B. F. Goodrich Company Research Center.

FRIDAY MORNING AT 9:45

Shoreham, Main Ballroom

(R. B. BRODE presiding)

Invited Papers on Cosmic Rays and Mesons

M1. Magnetic Properties of the Sun and Their Relation to Cosmic Radiation. MANUEL SANDOVAL VALLARTA, *Instituto Nacional de la Investigación Cientifica.* (30 min.)

M2. On Some Unusual Cases of Heavy Mesons (K and V_0) Observed in Photographic Emulsions. L. LEPRINCE-RINGUET, *Ecole Polytechnique.* (30 min.)

M3. Pion-Nucleon Scattering. S. W. BARNES, *University of Rochester.* (30 min.)

M4. Charge-Exchange Pion-Nucleon Scattering. J. H. TINLOT, *University of Rochester.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Shoreham, Terrace Room

(ARTHUR ROBERTS presiding)

Mesons, I.

N1. Scattering of 43-Mev Positive Pions by Hydrogen.* A. B. WEAVER AND J. J. LORD, *University of Washington,* AND JAY OREAR, *University of Chicago.*—Positive pions from the new 47-Mev pion beam of the Chicago cyclotron were passed through standard Ilford G5 plates to observe elastic scattering of the pions by hydrogen in the emulsion. A search was made by carefully examining a given area of the plate and analyzing the observed nuclear interactions. The pion-proton collisions were recognized by the coplanarity of the tracks, the angle between the tracks, and in three cases, the range of the recoil proton. A total pion track length of 26 800 cm was scanned and eight pion-proton collisions were identified. This leads to a total cross section of (9±4) millibarns. All of the events are backward scatterings except one where the center of mass angle is 84°. Such a strong backward scattering can be obtained by taking into account Coulomb interference and extrapolating the phase shifts obtained at higher energies by Anderson *et al.*[1] In this extrapolation the s wave phase shift

is assumed to be proportional to the momentum and the p waves to the cube of the momentum. Scanning is still in progress; additional data will be reported.

* Supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Submitted for publication in Phys. Rev.

N2. Differential Cross Sections for the Scattering of 58 Mev π^+ Mesons in Hydrogen.* D. BODANSKY, A. SACHS, AND J. STEINBERGER, *Columbia University.*—The cross sections have been measured for the scattering of 58 Mev π^+ mesons in liquid hydrogen using scintilation counters as detectors. The results, converted to the center-of-mass system, are:

Scattering angle	Differential cross section
36 degrees	0.24 ±0.11 mb/sterad
47	0.48 ±0.08
64	0.66 ±0.06
101	1.24 ±0.07
129	2.10 ±0.11
155	2.79 ±0.15

Assuming only s and p wave scattering, the phase shifts which give a best fit to the experimental points are $\alpha_s = -4.9$ degrees for the s^- wave phase shift, $\alpha_{p\frac{1}{2}} = -1.8$ degrees for the singlet p^- wave phase shift, and $\alpha_{p\frac{3}{2}} = +7.6$ degrees for the triplet p^- wave phase shift (or the corresponding $\alpha_{p\frac{1}{2}}$ and $\alpha_{p\frac{3}{2}}$ of the Yang type). A much poorer fit, which is not definitely precluded by the data but is considered very improbable, is given by the phase shifts: $\alpha_s = +7.4$ degrees, $\alpha_{p\frac{1}{2}} = +2.2$ degrees, and $\alpha_{p\frac{3}{2}} = -6.5$ degrees.

* Supported by joint contract of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

N3. Scattering of 120-Mev Negative Pions by Hydrogen.* JAY OREAR, *University of Chicago.*—Negative pions from the 122-Mev pion beam of the Chicago cyclotron were passed through standard Ilford G5 plates to observe scattering of the pions by the hydrogen in the emulsion. A total cross section for nonexchange scattering of (6.1±1.7) millibarns has been obtained based on 30 events. 400-micron plates exposed to 10^6 mesons cm^{-2} were "area scanned" for recoil protons under 830× magnification. A beam parallel within 1° was used so that incoming tracks of such high flux could still be resolved. Background events where the proton is of proper energy but the scattered pion fails to conserve momentum occur about six times more frequently than pion-proton scatterings. The application of energy-momentum conservation is sufficient to reduce this background to less than 7 percent of the effect. Scanning efficiency determinations give a value greater than 90 percent. The angular distribution shows forward and backward scattering about twice that at 90°. The recent liquid hydrogen results of Anderson *et al.*[1] are consistent with this angular distribution but give a somewhat higher total cross section of (11.3±1.6) millibarns.

* Supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Submitted for publication in Phys. Rev.

N4. Scattering of 169- and 192-Mev Pions by Hydrogen. R. L. MARTIN, E. FERMI, AND D. E. NAGLE, *University of Chicago.*—As part of a program to extend the measurements of scattering of pions by hydrogen, some results obtained for 169- and 192-Mev negative pions are reported. Differential cross sections in millibarns per steradian for elastic scattering in the laboratory system at 90° and 135° for 169-Mev pions are 0.7±0.2 and 1.5±0.3 and for 192-Mev pions 0.6±0.2 and 1.7±0.4. The exchange scattering gives rise to production of gamma-rays with cross sections at the same angles, 5.2±1 and 5.7±1 at 169 Mev and 3.4±1 and 5.6±1 at 192 Mev. The measurements are being repeated and extended and more complete values will be reported.

N5. Elastic Scattering of Negative Pi-Mesons in Aluminum.* AIHUD PEVSNER, ROSS WILLIAMS, AND JAMES RAINWATER, *Columbia University,* AND SEYMOUR J. LINDENBAUM, *Brookhaven National Laboratory.*—The elastic scattering of pions in aluminum is being measured. Preliminary results have been obtained for the angular distribution. A beam of focused mesons, 83±4 Mev, is defined by a scintillation telescope and the mesons scattered by ½-inch aluminum are detected by a second scintillation telescope. Three-fourths-inch copper is used before the last counter of the second telescope to stop all pions of less than 60-Mev energy. The angular distribution of scattering so obtained is similar to those obtained for carbon by others,[1] and will be shown. A broad minimum is obtained near 90°. The meson energy at the time of the scattering, including the effect of the aluminum target thickness, is 78±7 Mev. Checks are being made on the criterion of "elastic" by taking range curves of the scattered particles at various angles.

* This work was performed under the joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.
[1] Isaacs, Sachs, and Steinberger, Phys. Rev. **85**, 718 (1952); Byfield, Kessler, and Lederman, Phys. Rev. **86**, 17 (1952).

N6. Inelastic Scattering of Negative Pions.* GERSON GOLDHABER AND S. GOLDHABER, *Columbia University.*—Inelastically scattered π^- mesons observed in 600 μ Ilford G5 emulsions exposed at the Nevis cyclotron have been studied. The emulsions were exposed to a total flux of 3×10^4 π^- mesons per cm^2 with an energy of 135±10 Mev in the emulsion. The emulsions were scanned by area, and 440 meson interactions were found in an effective pion path length of 130±15 meters. Of these 22 percent were inelastic scatterings. Only those inelastic scattering events with scattered mesons of length $\geq 230\,\mu$ in the emulsion and dip angle $\leq 30°$ were considered in the angular and energy distributions. The energy of the scattered mesons was determined by grain density measurements and also by multiple scattering measurements for mesons of length $>1000\,\mu$. The angular distribution has a strong backward peaking and can be expressed as $d\sigma_{\text{lab}}/d\Omega = 1 - 0.8\cos\theta + 0.9\cos^2\theta$ in arbitrary units. The energy distribution shows that most of the scattered mesons have an energy loss from 70–110 Mev which cannot be explained on the basis of a single π-nucleon scattering in a nucleus. A comparison with data obtained by scanning along the track, where scattering events without prongs and small ($<50\,\mu$) prongs are also found, will be presented.

* This work was performed under the joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.

N7. Elastic Scattering in Nuclear Emulsions.* A. E. CLARK, R. A. GRANDEY, S. K. KAO, AND L. MANN, *Carnegie Institute of Technology.*—Ilford G5 emulsions 600 microns thick have been exposed to the high energy ion beams from the Carnegie Institute of Technology synchrocyclotron. The plates are scanned to find scattering events with the hydrogen in the emulsion using standard techniques.[1] The plates exposed to the 165±10 Mev negative pion beam were area scanned. 8±1 elastic events were found, giving a cross section: $\sigma = (13\pm5)\cdot10^{-27}$ cm^2. This is consistent with other data.[1,2] A few pion-proton scattering events have been found in plates exposed to the external 110-Mev negative and positive pion beams and to the 175-Mev internal positive pion beam. Twenty elastic $p-p$ collisions have been discovered in plates exposed to 435-Mev protons. The cross section $\sigma = (45\pm10)\cdot10^{-27}$ cm^2 is in agreement with counter data.[3] Three slow (4- and 5-Mev) proton recoils were found in heavy-water soaked plates exposed to 435-Mev protons. These events are supposed to be high energy $p-n$ collisions with the proton from the deuteron left behind. Assuming charge independence, 14 events should have been detected.

* Supported in part by the U. S. Atomic Energy Commission.
[1] G. Goldhaber, Phys. Rev. **87**, 220 (1952) and to be published; J. Orear (to be published).
[2] Anderson, Fermi, Long, and Nagel, Phys. Rev. **85**, 936 (1952).
[3] W. E. Mott and R. B. Sutton, Bull. Am. Phys. Soc., Cambridge Meeting, No. 1, January, 1953.

N8. A Study of 210-Mev Negative Pion Interactions. A. H. MORRISH, *McGill University*.—A stack of Ilford G5 emulsions were exposed to the 227-Mev negative pion beam of the University of Chicago synchrocyclotron. The average energy of the particles studied was 210±20 Mev, as determined by multiple scattering measurements. Individual tracks were followed to determine cross sections for "elastic" and "inelastic" scattering, stops and stars. In all 2823 cm of π^- meson track was examined, and the mean free path for a nuclear interaction was found to be 25.7 cm. Further, analysis of elastic scattering events gave a cross section for diffraction scattering of about 33 percent geometrical (πR^2). These measurements were supplemented with inelastic scattering and star events found from volume scanning. In particular, four inelastic scattering events were associated with a single charged particle, a fast proton. Only one of these had the prongs coplanar; the angles between the prongs agreed with those calculated assuming the event was a relativistic elastic meson-proton collision.

N9. $p+p\rightarrow d+\pi^+$ Cross Section at 340 Mev and 327 Mev. FRANK S. CRAWFORD, JR., AND M. LYNN STEVENSON, *University of California, Berkeley*.—The $p+p\rightarrow d+\pi^+$ differential cross section has been measured by detecting the meson and deuteron in coincidence. At 340 Mev measurements were made at 30°, 60°, and 90° in the c. m. The least square fit gives

$$\frac{d\sigma(\theta)}{d\Omega\,\mathrm{cm}} = 30[0.33\pm0.04+\cos^2\theta]\times10^{-30}\ \mathrm{cm}^2\ \mathrm{sterad}^{-1}.$$

At 327 Mev, measurements were made at 90° in the c. m. Using Schulz's[1] excitation function at 0° and the value at 0° for 340 Mev the cross section at 0° for 327 Mev is obtained. These data give

$$\frac{d\sigma(\theta)}{d\Omega\,\mathrm{cm}} = 20[0.38\pm0.11+\cos^2\theta]\times10^{-30}\ \mathrm{cm}^2\ \mathrm{sterad}^{-1}.$$

[1] Schulz, Hamlin, Jakobson, and Merritt, Phys. Rev. **87**, 219 (1952); University of California Radiation Laboratory Report, UCRL-1756.

N10. The Total Cross Sections for 37-Mev Pions in Hydrogen.* C. E. ANGELL AND J. P. PERRY, *University of Rochester*.—The total cross sections for the processes π^++P and π^-+P have been measured at a laboratory energy for the pion of 37±6 Mev. Assuming an isotropic angular distribution in the center-of-mass system for the scattering of pions by protons, and using the cross section given for the reaction $\pi^-+P\rightarrow\pi^0+N$[1], the cross sections are $\sigma(\pi^++P)=20.8\pm1$ millibarns and $\sigma(\pi^-+P)=21.0\pm2$ millibarns.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] A. Roberts and J. Tinlot, Phys. Rev. (to be published).

N11. Photomeson Production from Hydrogen and Deuterium at 180°.* T. R. PALFREY,† D. LUCKEY, AND R. R. WILSON, *Cornell University*.—Mesons produced by the 310-Mev bremsstrahlen of the Cornell synchrotron are analyzed by a 90° double-focusing magnet. The mesons produced in a target placed at the focus of the magnet are detected by a proportional counter telescope. The solid-angle and energy resolution are measured by means of a current-carrying wire. A correction is made for $\pi-\mu$ decay in flight. The differential center-of-mass cross section for π^+ mesons from hydrogen are 18.5±3.0 μb/sterad at $E_\gamma=234$ Mev and 21.1±2.6 μb/sterad at $E_\gamma=264$ Mev. Table I shows the differential cross section for production of mesons with energy E_π per Mev meson energy per steradian per effective quanta times 10^{32} cm^2. The following π^-/π^+ ratios were obtained at 180°:

Material	D, 46 Mev	Be, 46 Mev	Be, 64 Mev	C, 46 Mev	C, 64 Mev
Ratio	0.85±0.26	1.92±0.24	1.50±0.30	1.26±0.10	1.18±0.13

* Supported by U. S. Office of Naval Research.
† Now at Purdue University.

TABLE I.

E_π(Mev)	π^+, H	π^-, D	π^+, D	π^+, C
34	8.5±1.4	8.7±2.0	···	20.3±2.4
46	9.2±1.1	8.3±1.3	9.6±2.2	22.6±0.7
60	···	···	···	20.0±1.3

N12. Photomeson Production from Hydrogen and Deuterium at 90° and 30°.* D. LUCKEY, T. JENKINS, AND R. R. WILSON, *Cornell University*.—Using the double-focusing magnet described in the preceding abstract, we have measured mesons produced by 310-Mev bremsstrahlen. Results for π^+ production from hydrogen at 90° in the laboratory system are given in Table I. The value at 283 Mev is a lower limit

TABLE I.

E_γ	202 (Mev)	217 (Mev)	234 (Mev)	258 (Mev)	283 (Mev)
$d\sigma/d$ in μb/sterad	14±2	16±2	18±1	23±1	22±1

since the effect of saturation on the detection efficiency at this energy has not as yet been measured. Table II shows the

TABLE II.

Material	34 Mev	44 Mev	54 Mev	70 Mev	84 Mev
H, π^+	9.1±1.1	9.7±1.1	10.6±0.4	13.0±0.7	11.2±0.6
C, π^+	23.0±1.6	26.9±1.4	25.2±1.4	19.8±0.7	14.8±0.7
D, π^-	7.0±1.1	7.9±1.4	11.5±1.1	9.0±0.7	8.5±0.9
D, π^+	6.6±1.7	···	7.7±1.1	···	6.5±1.5

differential cross section for production of mesons per Mev meson energy per steradian per effective quanta times 10^{32} cm^2 *versus* meson energy. At 30° lab, 37° c. m., the cross section for 234-Mev photons on H is 9±1 μb/sterad. Work is being extended to other angles and energies.

* Supported by U. S. Office of Naval Research.

N13. Angular Distribution of π^+ Mesons from 320-Mev Photons on Protons.* Y. GOLDSCHMIDT-CLERMONT, L. S. OSBORNE, AND A. W. WINSTON, *M.I.T.*—π^+ mesons were produced by the γ-ray beam of the M.I.T. 350-Mev electron synchrotron. The γ-ray beam had a duration of about 1 μ-second, and the mesons were detected after the passage of the beam by measuring the electrons from the μ^+ decay in scintillation counters. Counting rates were obtained for CH_2 and carbon; the proton cross section was obtained by subtraction. The relative cross section in the center-of-mass system of the proton and γ-ray at various angles is given below:

θ (center-of-mass)	30°	90°	150°
σ (relative)	0.33±0.12	1.00±0.12	1.21±0.12

Assuming the cross section as a combination of P^1 and S wave mesons, this gives the fraction of P state as 50 percent±15 percent and the relative phase angle as $37^{\circ}{}^{+15^{\circ}}_{-27^{\circ}}$.

* This work was supported in part by the joint support of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

N14. Positive Photomesons from Hydrogen at 0°. R. STEPHEN WHITE, GORDON W. REPP, AND NELSON JARMIE, *University of California, Berkeley*.—Hydrogen gas has been bombarded in a high pressure, low temperature target[1] by 322-Mev bremsstrahlung from the Berkeley synchrotron to produce π^+ mesons at 0±4 degrees to the beam. The π^+ mesons were bent out of the beam with a magnetic field. The

mesons passed through a lead channel and lead absorbers and were detected in Ilford C2 emulsions. Data have been obtained for a photon energy of 278±4 Mev (meson kinetic energy of 135±4 Mev). The absolute differential cross section in the center-of-mass system for the reaction $\gamma+p\rightarrow\pi^{+}+n$ is

$$\frac{d\sigma}{d\Omega}=(6.2^{+2.8}_{-1.9})\times10^{-30}\ \text{cm}^2\ \text{sterad}^{-1}.$$

This point may be combined with data[1] at other angles for a 275-Mev photon to evaluate the constants in $a+b\cos\theta+c\sin^2\theta$, a form suggested by the isobar theory.[2] The least squares fit of the above equation to the experimental data will be compared to theoretical values of Brueckner and Watson.[2]

[1] White, Jakobson, and Schulz, Phys. Rev. **88**, 836 (1952).
[2] K. A. Brueckner and K. M. Watson, Phys. Rev. **86**, 923 (1952); B. T Feld, Phys. Rev. **89**, 330 (1953).

FRIDAY AFTERNOON AT 2:00

NBS, Materials and Testing

(F. N. FRENKIEL presiding)

Fluid Dynamics

NA1. Design and Calibration of Total-Temperature Probes for Use at High Supersonic Speeds and Elevated Temperatures. EVA M. WINKLER, *U. S. Naval Ordnance Laboratory.*—Shielded and vented thermocouple probes were used for total-temperature measurements in the free stream and the boundary layer of the NOL hypersonic wind tunnel over a wide range of Mach numbers, supply temperatures, and Reynolds numbers. The design of the probes is described and calibration data are presented. For a particular probe, the calibration data cover a Mach number range from 2.3 to 8 at corresponding Reynolds numbers between 70 000 to 9000 with stagnation temperatures ranging from 300 to 700°K. Up to Mach numbers of about 5 and Reynolds numbers larger than 25 000, the probe temperature recovery factor is 0.998. For Mach numbers above 5, the calibration data were obtained for Reynolds numbers smaller than 25 000 and at elevated temperatures only, given by the particular operational range of this hypersonic wind tunnel. Under these conditions the temperature recovery factor of the probe is lower. For fixed Mach number, the temperature recovery factor of the probe decreases with decreasing Reynolds number. This is due to the relative increase of conduction and radiation losses with respect to the heat transfer by convection. The magnitude of this decrease is dependent on the stagnation temperature for given Mach and Reynolds number.

NA2. Heat Transfer on a Hemispherical Body in Supersonic Flow. IRVING KOROBKIN, *U. S. Naval Ordnance Laboratory.*—Distributions of pressures, equilibrium temperatures, and heat transfer coefficients were measured on a hemisphere-cylinder at Mach number 2.8 in the NOL supersonic wind tunnels. Temperature recovery factors, based on local flow conditions obtained from the pressure distribution, were determined from equilibrium surface temperature measurements. Heat transfer coefficients, evaluated under transient heating and cooling conditions, were correlated in terms of the dimensionless parameters, Nusselt number, and Reynolds number. The calculated ratio, Nusselt/Reynolds$^{0.5}$, was compared with an extension of theoretical results obtained by Sibulkin[1] for a laminar boundary layer in incompressible flow. The experimental results on the hemisphere followed the theoretically predicted trend but were about 20 percent lower near the stagnation point. The experimental results on heat transfer coefficients were subject to a scatter of ±15 percent.

[1] M. Sibulkin, J. Aeronaut. Sci. **19**, 570–571 (1952).

NA3. Experiments on a Phosphorescence Method for Study of Surface Temperatures in a Supersonic Flow Field.* L. C. BRADLEY, C. C. VAN VOORHIS, AND D. BERSHADER, *Princeton University.*—By use of thin sheets of plastic material impregnated with a temperature-sensitive phosphor,[1] whose emission was capable of temperature resolution of at least a tenth of a degree, photographs have been obtained of the temperature distribution on an insulated plane surface in the Palmer Laboratory 3 in.×3 in. intermittent supersonic wind tunnel (M=2.3). Excitation by ultraviolet light from a mercury arc produced satisfactory light intensity which increased with a decrease of temperature. Preliminary studies have been concerned with boundary layer transition and "transverse contamination," the regions of laminar and turbulent flow being rather well defined. Results so far indicate: (1) a spanwise variation of transition, which had been previously interpreted as a transition region by optical methods of the integrating type,[2] (2) turbulent contamination from the tunnel wall boundary layers spreading at an angle in the range 5°–10°, and (3) the possibility that a slight blunting of the leading edge may increase the transitional Reynolds number. Additional applications under study include quantitative analysis of recovery temperatures and heat transfer coefficients.

* Research assisted by the U. S. Office of Naval Research.
[1] Urbach, Nail, and Pearlman, J. Opt. Soc. Am. **39**, 1011 (1949).
[2] R. Ladenburg and D. Bershader, Revs. Modern Phys. **21**, 510 (1949).

NA4. Cylindrical Couette Flow. MARIAN ROSE, *New York University.*—The steady flow of a rarefied gas between rotating concentric cylinders is investigated using Grad's thirteen-moment method of obtaining an approximate solution to the Boltzmann equation.[1] The thirteen differential equations thus obtained for the parameters of the gas cannot be solved in closed form when expressed in cylindrical coordinates, even though the parameters depend on only one independent variable, namely, the distance between the cylinders. Hence it becomes necessary to resort to expansion methods. The differential equations and boundary conditions are expanded in terms of (a) inverse powers of the radius, (b) powers of the Mach number, (c) inverse powers of the mean free path. In case (a), the first approximation, i.e., the plan Couette flow case has been solved in closed form by Grad using the thirteen-moment method. In the higher order approximations, the parameters of the gas can all be expressed in terms of the temperature which can be determined from the differential equation which it satisfies. These results will be valid at all Mach numbers. In case (b) the results will be valid only at low Mach numbers but for all radii; whereas in case (c) the results should hold for all radii and Mach numbers when the mean free path is sufficiently large.

[1] H. Grad, Communs. Pure Appl. Math. **2**, No. 4 (1949).

NA5. The Use of the Shock Tube for Studying Chemical Kinetics.* A. HERTZBERG AND W. SQUIRE, *Cornell Aeronautical Laboratory, Inc.*—A modified shock tube is described for studying the kinetics of chemical reactions with a charac-

teristic time on the order of 10^{-3} sec at high temperatures. The reactant sample is heated by a strong shock wave and then cooled rapidly by an expansion wave to freeze the reaction. Calculations show that extremely high temperatures and cooling rates can be obtained under closely controlled conditions.

* This research was conducted under the auspices of Project SQUID, jointly sponsored by the Office of Naval Research and the Office of Air Research.

NA6. Shock Tube Studies of Transient Boundary Layers in Compressible Flow.* DANIEL BERSHADER, *Princeton University.*—The brief period (about one millisecond in the present work) of nearly uniform flow behind a traveling plane wave in a shock tube has been utilized to study the change with time of a boundary layer, believed laminar, on the flat side of a 10° steel half-wedge placed in the tube at zero angle of attack in a flow field of Mach number 1.16. Density distributions were measured by interferometry at approximately 0.1-millisecond intervals starting at 0.1 millisecond after passage of the shock. Reliability of the results was checked by computations which showed refraction and corner effects to be unimportant. Under conditions of the experiments, the distances from the two effective leading edges (the shock wave itself constituting a leading edge in motion) were of the same order of magnitude, leading to the general conclusion that the measured distributions should lie between the strictly time-dependent (in which the only length is distance from the surface, as in Lord Rayleigh's classic problem) and the steady state profiles, asymptotically approaching the latter with increasing time. Such, in fact, appears to be the case.

* Research assisted by the U. S. Office of Naval Research.

NA7. A Generalized Theory of Mach Reflection of Shock Waves. BERTHOLD ZARWYN (introduced by G. E. Hudson).—The elementary three-shock configuration theory predicts inaccurately the limits of occurrence of Mach reflection. More refined theories which attempt to find a solution of the flow field, such as the theories of Bargmann, Lighthill, Ting, and Lindloff, are limited to glancing angles of incidence of the shock due to the adoption of a linearization procedure. This paper suggests a variational approach to the problem, both in the specialized form of plane wall reflection and the more general form of reflection at an arbitrary boundary, which lends itself readily to arbitrary angles of incidence. The variational equations for the Mach configuration are derived and boundary conditions are formulated. Galerkin's method is used in setting up the variational system of equations. The method has the advantage that the solution can be obtained in one step due to the introduction of undetermined parameters, which specify the changing boundary conditions. The value of the method is substantiated by a numerical example. A brief outline of a novel general method is given, which renders nonstationary flow problems with general analytical boundary conditions amenable to numerical analysis.

NA8. On the Asymmetry of Turbulent Functions.* R. BETCHOV, *University of Maryland.*—A simple incompressible flow has been studied with a hot wire anemometer. The joint probability distribution of u (velocity fluctuation parallel to the main flow) and du/dt have been observed on a cathode-ray tube and the mean values of u^3 and $(du/dt)^3$ have been measured with a chain of diodes, as well as the mean squares. The results of these observations have been compared with the response of an electric resonant circuit excited by a random noise. The circuit includes, in addition to the usual elements analogous to inertia and restoring force, either a nonlinear damping term $k(u)du/dt$ or a variable damping term $k(t)du/dt$, where $k(t)$ is another given random function.

* This work is supported by the U. S. Office of Air Research and Development Command.

NA9. Compressible Flow of a Viscous Fluid in a Capillary Connected to a Closed Vessel. J. M. KENDALL, *U. S. Naval Ordnance Laboratory.*—The basic nonlinear differential equation for a compressible viscous fluid flowing isothermally through a capillary connected to a closed vessel whose volume is a function of pressure is solved under the assumption that the flow in the capillary is in a quasi steady-state condition. The solution giving the pressure in the vessel as a function of time in response to a step function of pressure is obtained in a straightforward manner. If, however, the pressure in the capillary is sufficiently low that the mean free path is no longer much smaller than the capillary radius, a numerical procedure is required for obtaining the solution. The principal effect of the slip is to reduce the flow resistance slightly, thereby giving a shorter time required for the pressure in the vessel to reach a given percentage of the final pressure. The experimentally measured pressures as a function of time were found to be in good agreement with the calculated values.

NA10. Pressure and Temperature Distribution on a Circular Cylinder in Supersonic Cross Flow. LLOYD W. WALTER, *U. S. Naval Ordnance Laboratory.*—Surface pressure and equilibrium temperature were measured on a Lucite cylinder of ½-inch diameter placed perpendicularly to the flow in the continuous 18×18 cm aerophysics wind tunnel at NOL. The cylinder completely spanned the tunnel. The tests were made at M=2.5, 2.8, 3.2, and 4.9 with a corresponding Reynolds number range (based on cylinder diameter) from 140 000 to 40 000. It was found that the pressure coefficient distributions up to the separation point are nearly independent of Mach number; the temperature distribution, however, showed some scatter. Surface pressure coefficient and surface to supply temperature ratio between the two separation points for azimuthal angles larger than about 120° are constant for every Mach number. This constant pressure coefficient increases and the temperature ratio decreases with Mach number. Finally drag coefficients obtained from measured pressure distribution and theoretical skin friction calculations are given and schlieren pictures indicating a turbulent wake are shown.

FRIDAY AFTERNOON AT 2:30

NBS, East Building

(K. F. HERZFELD presiding)

Solid-State and Liquid-State Physics

P1. Storage of Energy in KCl-Tl and NaCl-Tl.* C. E. MANDEVILLE AND H. O. ALBRECHT, *Bartol Research Foundation.*—The phosphorescence and energy storage properties of KCl-Tl and NaCl-Tl have been investigated with the use of photosensitive Geiger counters and photomultiplier tubes. The photostimulated emission of the ultraviolet band was

observed at intervals of 24 hr over a period of 96 hr after initial excitation by a dosage of approximately twenty roentgens of x-rays. The storage characteristics will be compared with those of NaCl-Ag and KCl-Ag. The emission bands of these phosphors have been measured under alpha-particle bombardment, and have been found to be centered at 3000A and 4000A for KCl-Tl and 2950A and 3900A for NaCl-Tl.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

P2. Phosphorescence of and Energy Storage in Silver Activated Sodium Chloride.* H. O. ALBRECHT AND C. E. MANDEVILLE, *Bartol Research Foundation.*—The concentration of silver in NaCl+0.1 percent AgCl has been diluted by a factor of five, three successive times to produce polycrystalline phosphors of AgCl content 0.02 percent, 0.004 percent, and 0.0008 percent by weight. Specimens of each concentration have been irradiated for 1 hr in a radiation field of intensity $\sim 20r$/hr and stored in darkness. The photostimulated output of ultraviolet has been observed simultaneously with photostimulation during six second bursts at intervals of twenty-four hours after initial excitation by x-rays. Some additional data will be presented concerning the decay laws of the normal unstimulated phosphorescence of the two emission bands of NaCl-Ag.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

P3. Energy Band Crossings for Periodic Square Well Potentials. G. ALLEN AND ROLF LANDAUER.*—The energy band structure for a one-dimensional periodic square well potential has been examined numerically and analytically as a function of the well depth. This has been done for the whole range of possible ratios of well length to hill length. As the potential depth is varied for a fixed ratio of well length to hill length, adjacent bands will come together, touch at one point, and separate again. These zone boundary crossings occur for every finite ratio of well to hill length, but not for the Kronig-Penney potential. The location of these crossings has been derived. The number of times that a given pair of boundary curves can cross and recross has been considered. For the set of boundary curves that belong to a given ratio of well to hill length, this number is unbounded.

* Now with the International Business Machines Corporation.

P4. Crystalline Electric Field in Neodymium Bromate. R. A. SATTEN, *M.I.T.*—An attempt has been made to determine the local crystalline electric field about the Nd^{+++} ion in the bromate crystal which is necessary to produce the observed[1] splitting of certain J levels of the free ion. The most general potential in this case is of the form $V=A_2V_2+A_4V_4+A_6V_6+A_6^6V_6^6$, where the V_L^M are sums over the $4f$ electrons of spherical surface harmonics Y_L^M, and the A_L^M are adjusted to the data. The order of the electrically split levels is decided by determining $|A_2|$ from the known splitting of $^4F_{3/2}$, A_4 from $^4G_{5/2}$, A_6 and A_6^6 from $^4I_{9/2}$. The M dependence of the matrix elements was found from the table of Stevens,[2] and the LSJ dependence of excited states from eigenfunctions. The results indicate that all four of the A_L^M are important with the quadrupole term A_2V_2 having a small effect on the $^4I_{9/2}$ ground term splitting. The latter splits into five doubly degenerate levels as follows (in order of increasing energy): (1) $M=\pm 5/2$, $\mp 7/2$; (2) $M=\pm 3/2$, $\mp 9/2$; (3) $M=\pm 9/2$, $\mp 3/2$; (4) $M=\pm 1/2$; (5) $M=\pm 7/2$, $\mp 5/2$, where for each level the $\pm M$'s contributing the most to the eigenfunctions are stated first. The effect of intermediate coupling is also being investigated and will be reported on.

[1] R. A. Satten, J. Chem. Phys. **21**, 637 (1953).
[2] K. W. H. Stevens, Proc. Phys. Soc. (London) **65A**, 213 (1952).

P5. Transparent, Nonmetallic, Electrically Conducting Film Applications. L. B. CLARK, SR., *Naval Research Laboratory* (introduced by F. N. D. Kurie).—Visibly transparent, nonmetallic, electrically conducting films, similar to the iridescent decorative films used on glass and ceramic articles, have been produced by a new method. The films are deposited from the gas phase, and can be made of uniform thickness as shown by their interference color in white light. The method of producing the films is described and applications are suggested. These applications include cathodes in Geiger-Müller counting tubes, high megohm resistors, telemetering devices, fire detectors, and shaped films giving tailored resistances. Halogen quenched Geiger tubes are described in which these films, deposited on the internal surfaces of glass tubes, are used as cathodes. These tubes are rugged, long-lived, nonphotosensitive, easily made, and use no critical materials.

P6. The Effects of Grooves in Piezoelectric Filter Plates.* CHARLES R. MINGINS, ROBERT W. PERRY, AND DAVID W. MACLEOD, *Tufts College.*—The result of cutting shallow grooves in alignment on opposite principal surfaces of a single-plate piezoelectric filter is at first to move the fundamental thickness-shear resonance to a higher frequency while having little effect upon the frequency of the 1,2,1 mode. The consequence is a narrowing of the pass band of the filter. As the grooves are deepened, however, the trend of the fundamental frequency is brought to a halt and then reversed, so that further deepening can depress this frequency substantially below its original value in the ungrooved state and, since the 1,2,1 mode is still little affected in frequency, can more than double the width of the pass band. The behavior of the motional inductances, capacitances, and resistances[1] in the effective network of the plate has been investigated as such; changes were made, and the variations in these parameters are discussed. The mechanical, elastic, and inertial effects, and the electromechanical effect must be examined separately; their relative importance in producing changes is a function of the depth of the grooves.

* This work is sponsored by the U. S. Signal Corps.
[1] Frost, Mingins, and Perry, Phys. Rev. **88**, 154 (1952).

P7. An Electric Wave Filter Combining Piezoelectric Divided Electrode Units.* ALBERT D. FROST, CHARLES R. MINGINS, AND LAWRENCE A. HOWARD, *Tufts College.*—Certain inherent characteristics of a single piezoid with divided electrodes limit its application as a band-pass filter of the transmission type. While satisfactory transmission characteristics are obtainable with such units[1] by the combined effect of the fundamental and 1,2,1 thickness-shear resonances, this simple form of filter unit is limited because of impedance-matching difficulties to band widths in the lower part of the desired range. At larger widths the fluctuations of the characteristic within the nominal pass band become excessive. Unfortunately, the introduction of additional higher mode plate resonances by such techniques as variations in plate geometry and in electrode configurations is shown to yield only separated bands, and therefore cannot either improve the transmission characteristics within the band or extend the band width. The situation can be improved, however, by combining the resonances of two plates in a balanced circuit. Equivalent networks for such arrangements are presented, together with a consideration of the practical and theoretical limitations involved in their design.

* This work is sponsored by the U. S. Signal Corps.
[1] Mingins, Bartnoff, and Howard, Phys. Rev. **88**, 154 (1952).

P8. Fourier Transforms of Shells and Intensities from Crystalline Proteins.* DOROTHY WRINCH, *Smith College.*—Studies of x-ray data from crystalline proteins suggest that native proteins may have molecular skeletons comprising interlocked amino acid backbones, of characteristic construc-

tion, which are globulite in shape and cage-like in nature, the various proteins being composed of several numbers of such skeletons, variously substituted and in various spatial patterns.[1] In this case, the pronounced 8–12A and 4–5A scattering found for many proteins may be primarily intra-skeletal in origin and may, indeed, correspond to the first and second regions of high density in the $|F|^2$ distributions for individual skeletons. The Fourier transforms of various types of uniform shell distributions,[2] with positive and also with negative interiors, are therefore being investigated. Results which can be correlated with the two sets of spacings, 8–12A and 4–5A, have been obtained for spherical shells and for shells of polyhedral types: they indicate that any such shells would have relatively small dimensions.

* Supported by the U. S. Office of Naval Research.
[1] D. Wrinch, J. Chem. Phys. **20**, 1332 (1952).
[2] D. Wrinch, "Fourier transforms and structure factors" (1946).
[3] D. Wrinch, Phys. Rev. **86**, 611 (1952).

P9. Neutron Diffraction by Liquid Oxygen, Nitrogen, and Argon. D. G. HENSHAW, D. G. HURST, AND N. K. POPE, *Atomic Energy of Canada Limited.*—Measurements of the scattering of 1.08A neutrons from liquid oxygen at a temperature of 90°K, nitrogen at 77.4°K, and argon at 86.3°K were made over the angular range 4° to 78°. The results, corrected for multiple scattering, background, and resolution were assumed to represent coherent scattering to which the transformation well known in x-ray work may be applied. The transforms relate the differential cross section to the atomic density as a function of distance from an atom. Some conclusions drawn are (1) the deviation from the mean density is an oscillating function of r whose amplitude decreases somewhat more rapidly than r^{-3}, (2) the existence of a discrete peak in nitrogen of nearly unit area at 1.1A corresponds to diatomic molecules in the liquid, (3) a peak in oxygen at 1.3A can be interpreted as due to a mixture of O_2 and O_4[1]; unlike x-ray results, only a single peak is found between 0 and 2.5A. It must be borne in mind that the conclusions are valid only to the extent to which it is justified to treat the scattering of neutrons by these liquids as coherent.

[1] G. N. Lewis, J. Am. Chem. Soc. **46**, 2027 (1924).

P10. The Effects of Heat Treatment on Lattice Perfection.* NORMAN W. LORD, *Raytheon Manufacturing Company.*—If we associate with a lattice vacancy generating mechanism, such as that proposed by Nabarro,[1] a rate process equation for the relaxation to thermodynamic equilibrium, the effect of an arbitrary heat treatment may be calculated. For the simple example of a first-order rate equation and an exponentially falling temperature, the added concentration of vacancies $\phi(T)$ at any temperature during the fall is the solution of the linear integral equation,

$$\phi(T) = -(A)(B)\int_{T_i}^{T} \frac{\left[e^{-W_1/kT} - (e^{-W_1/kT_0} + \phi(T))\right]}{(T - T_f)} \tau_2 e^{-W_2/kT} dT,$$

where A, B are constants, W_1 is the energy of formation of a vacancy, W_2 the energy required for migration of a vacancy, T_2 the time constant of the heat treatment, T_i, T_f the initial and final temperatures, and T_0 the temperature corresponding to the previously existing vacancy concentration. Approximative procedures and generalizations will be discussed.

* Work performed under contract with the Bureau of Ships.
[1] F. R. N. Nabarro, Conference on Strength of Solids (London) (1948), p. 75.

P11. Shapes of Floating Liquid Zones Between Solid Rods. P. H. KECK, M. GREEN, AND M. L. POLK, *Signal Corps Engineering Laboratories.*—The floating zone method has been previously described.[1] The present paper seeks to describe the shapes of liquid floating zones between solid rods of silicon and of germanium and to establish stability conditions. The shapes were deduced from the equation given by Laplace,

$$p = \gamma[(1/R_1) + (1/R_2)],$$

where p indicates the pressure difference across the surface membrane of a liquid at any point, R_1 and R_2 are the principal radii of curvature at that point, and γ is the surface tension of the liquid. The floating liquid zone is analyzed within a wide range of dimensions up to the maximum for stability. These dimensions were theoretically determined and experimentally confirmed.

[1] P. H. Keck and M. J. E. Golay, Phys. Rev. **89**, 1297 (1953).

FRIDAY AFTERNOON AT 2:00

Shoreham, West Ballroom

(V. F. WEISSKOPF presiding)

Reactions of Transmutation and Inelastic Scattering, II

PA1. Gamma-Rays from the Disintegration of C^{13} by Deuterons.* R. D. BENT, T. W. BONNER, AND R. F. SIPPLE, *Rice Institute.*—Using a pair spectrograph of improved design the pair line from $F^{19}+H^1$ at 6.05 Mev has been observed with 2.8 percent resolution. We have also investigated the suspected "pair line" at 4.1 Mev from the bombardment of C^{13} by deuterons,[1] but only obtained relatively weak lines attributed to γ-radiation with energies of 3.4, 4.5, 5.0, 5.2, 5.8, and 6.2 Mev.

* Supported by the U. S. Atomic Energy Commission.
[1] R. G. Thomas and T. Lauritsen, Phys. Rev. **88**, 969 (1953).

PA2. Angular Distribution of Neutrons from $C^{14}(p, n)N^{14}$.* ROBERT KAY, HANS MARK, AND CLARK GOODMAN, *M.I.T.*—Experimental and theoretical difficulties have limited the application of angular distribution measurements of neutrons from (p, n) reactions for spin and parity assignments. The angular distribution of neutrons from the $Li^7(p, n)Be^7$ reaction has been studied previously.[1] A long counter was used as a neutron detector in these earlier experiments. Using a proton recoil counter which is insensitive to neutrons with energies less than 100 kilovolts, we have investigated the angular distribution of neutrons from the reaction $C^{14}(p, n)N^{14}$. Four resonances[2] (2, 3, 7, and 8) have been studied at proton energies 1.165, 1.310, 2.024, and 2.079 Mev. Resonances 2 and 3 yield isotropic distributions. Resonances 7 and 8 show strong anisotropic distributions. The spin and parity assignments which can be tentatively made from these results appear to agree with the values previously obtained[3] by the total neutron cross section measurement on N^{14} (mainly $N^{14}(n, p)C^{14}$).

* Work jointly supported by the U. S. Office of Naval Research and the Bureau of Ships.
[1] R. Taschek and A. Hemmendinger, Phys. Rev. **74**, 373 (1948); Willard, Preston, and Goodman, Massachusetts Institute of Technology LNSE Technical Report, No. 45 (1950).
[2] Roseborough, McCue, Preston, and Goodman, Phys. Rev. **83**, 1133 (1951).
[3] Hinchey, Stelson, and Preston, Phys. Rev. **86**, 483 (1952).

PA3. Inelastic Scattering of Alphas from N^{14}.* B. M. CARMICHAEL, M. B. SAMPSON, AND O. E. JOHNSON, *Indiana University.*—Alpha-particles accelerated to 21.2 Mev by the Indiana University cyclotron have been used to bombard N_2 gas at 0.05 atmos pressure. The ranges of the inelastically scattered alpha-groups in aluminum were measured at 35 degrees. Levels in N^{14} at 4.10, 4.44, 5.22, 5.72, 6.01, 6.68, 7.03, 7.95, 8.64, and 9.23 Mev are found from the Q values of these alpha-groups. No alpha-group leading to the 2.3-Mev level established by other reactions was observed. It has been predicted that this level should not be excited in the reactions $N^{14}(\alpha, \alpha')N^{14*}$, $N^{14}(d, d')N^{14*}$, and $O^{16}(d, \alpha)N^{14*}$ since isotopic spin conservation would be violated.[1] The nonexcitation of this level by the latter two reactions has been previously reported.[2,3]

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] R. K. Adair, Phys. Rev. **87**, 1041 (1952).
[2] Browne, Bockelman, Buechner, and Sperduto, Bull. Am. Phys. Soc. **28**, No. 1, 11 (1953).
[3] Craig, Donahue, and Jones, Phys. Rev. **88**, 808 (1952).

PA4. Energy Levels in N^{15}.† A. SPERDUTO, W. W. BUECHNER, M. M. ELKIND,* AND W. J. FADER, *M.I.T.*—In a continuation of previous work[1] on the $N^{14}(d, p)N^{15}$ reaction, proton groups from Nylon targets bombarded with deuterons have been analyzed with a magnetic spectrograph. Protons from nitrogen were distinguished from those from carbon and oxygen by comparison bombardments of Formvar and polyethylene targets and by measurements made as a function of deuteron energy. Deuteron energies from 5 to 8 Mev were used, and the region of excitation covered in N^{15} was from 7.5 to 10.8 Mev. In this region, the results thus far indicate excited states at 7.58, 8.31, 8.57, 9.05, 9.16, 10.06, 10.45, 10.53, 10.69, and 10.80 Mev. This overlaps the region covered in earlier work carried out with 1.4-Mev deuterons, where the highest level found was at 8.31 Mev. In the earlier work, a proton group corresponding to the 7.58 level would have been obscured by one from $O^{16}(d, p)O^{17}$.

† This work has been supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
* From the Laboratory of Biophysics, National Cancer Institute, National Institutes of Health, Bethesda, Maryland.
[1] R. Malm and W. W. Buechner, Phys. Rev. **80**, 771 (1950).

PA5. Analysis of the $N^{15}(p, \alpha)C^{12}$ Excitation Function. W. A. FOWLER, *California Institute of Technology,* AND R. G. THOMAS, *Los Alamos Scientific Laboratory.*—This excitation function exhibits broad resonances at 0.34 and 1.03 Mev in addition to a narrow 4^+ resonance at 1.21 Mev.[1] Between the broad resonances there is pronounced constructive interference, and the differential cross sections there are equal at 90 and 138°. Considering this, the large γ-ray width at 1.03 Mev, and Wigner's limit, it is most likely that both are $J=1^-$, $l_p=0$. The excitation function is analyzed in detail by means of Wigner's two-channel formula,[2] including the external Coulomb interactions. Two levels with resonance parameters $E=0.335$, $\gamma_p^2=1.3$, $\gamma_\alpha^2=0.07$, and $E=1.035$ Mev, $\gamma_p^2=1.8$, $\gamma_\alpha^2=0.04\times10^{-13}$ Mev·cm, are sufficient to adequately describe $\sigma(E)$ from 0.20 to 1.4 Mev, a difference in sign of the products $\gamma_p\gamma_\alpha$ being responsible for the constructive interference. A reasonable contribution from other 1^- levels to the nondiagonal components of the R matrix can account for $\sigma(E)$ below 0.20 and above 1.4 Mev. The effects of the diagonal contributions to R from other levels, the energy dependences of the external wave functions, and the choice of the boundary conditions on the determination of the actual level parameters are considered. The stellar cross sections predicted by this analysis agree with the previous predictions.[1]

[1] Schardt, Fowler, and Lauritsen, Phys. Rev. **86**, 527 (1952).
[2] E. P. Wigner, Phys. Rev. **70**, 606 (1946).

PA6. The Mechanism of the Reaction $O^{16}+h\nu\rightarrow 4\,He^4$.† C. A. HSIAO AND V. L. TELEGDI, *University of Chicago.*—The reaction $O^{16}+h\nu\rightarrow 4\,He^4$ has been investigated by inducing "oxygen stars" in E1 emulsions with 48-Mev bremsstrahlung. While it is known[1] that for $h\nu<23$ Mev this reaction goes in 50 percent of the cases via an excited state of C^{12} ($E_c^*=9.7$ Mev) and the ground state of Be^8 ($E_{Be}^*=0.1$ Mev), we conclude from 240 events that the mechanism changes abruptly at $h\nu\simeq24.5$ Mev. Above this energy practically all events ($\sim$90 percent) involve a level with $E_c^*\cong16$ Mev and 1.8 Mev *experimental* half-width, and $E_{Be}^*\cong3$ Mev. This situation is understood[2] if one assumes: (a) E1 absorption, (b) charge independence of nuclear forces, and (c) one or more $T=1$ levels in C^{12} near 16 Mev. Carbon levels[3] at 15.09 and 16.07, corresponding to the ground and first excited states of B^{12}, respectively, make (c) plausible. A few events involving $E_c^*\cong26.5$ Mev and $E_{Be}^*\cong17$ Mev were also found, thus bearing out a theoretical prediction.[2] For $22.5<h\nu<24.5$ Mev mainly $E_c^*\cong13$ Mev seems to be involved, a fact which cannot be understood from T selection rules.

† Work supported by contract with the U. S. Office of Naval Research.
[1] Goward and Wilkins, Proc. Phys. Soc. (London) **63A**, 1171 (1950).
[2] Gell-Mann and Telegdi, Phys. Rev. (to be published).
[3] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 321 (1952).

PA7. Angular and Energy Distributions of Photoprotons from Aluminum and Tantalum.* A. G. W. CAMERON AND M. M. HOFFMAN, *Iowa State College.*—Foils of aluminum and tantalum were irradiated at energies of from 25 to 65 Mev in the synchrotron x-ray beam. Photoprotons produced at various angles were recorded in nuclear emulsions. Those emitted with low energies appear isotropically distributed and have energy distributions characteristic of statistical evaporation processes. The higher energy protons from aluminum have an angular distribution of the form $(\sin\theta+p\sin\theta\cos\theta)^2$ with $p\approx0.7$, whereas those from tantalum have a nearly pure $\sin^2\theta$ distribution. Their energy distributions can be represented in the form E_p^{-n}, where E_p is the proton energy. For aluminum sharp increases in the exponent n occur at a value of E_p slightly greater than half the maximum photon energy of the irradiation. The increases are considerably less in the case of tantalum. The aluminum results are qualitatively consistent with Levinger's quasi-deuteron model of the nucleus. None of the proposed photon interaction models gives a good explanation of the tantalum results.

* Work was performed at the Ames Laboratory of the U. S. Atomic Energy Commission.

PA8. The $A^{36}(n,\alpha)S^{33}$ Reaction.* B. J. TOPPEL AND S. D. BLOOM, *Brookhaven National Laboratory.*—A preliminary investigation of the (n,α) reaction in argon[1] has been made using an argon filled proportional counter of known sensitive volume. Comparison of results obtained with normal argon and enriched argon[2] identified A^{36} as the isotope responsible for the observed groups in the pulse height distribution. Using D-D neutrons, observations at 4.40, 3.73, 3.23, 2.76, and 2.15 Mev, all ±0.10 Mev, yielded a Q-value of 2.0 ± 0.1 Mev for the highest group, and a second Q, 0.9 ± 0.1 Mev lower, for the next group. The calculated Q for $A^{36}(n,\alpha)S^{33}$ is 1.92 ± 0.13 Mev and the first excited state of S^{33} is at 0.87 ± 0.04 Mev,[3] in agreement with the above results. Cross sections listed below have been calculated using published D-D cross sections.[4]

Neutron Energy, Mev:	4.40 ± 0.10	3.76 ± 0.10	3.23 ± 0.10	2.76 ± 0.10	2.15 ± 0.10
σ, mb $A^{36}(n,\alpha)S^{33}$:	208 ± 63	113 ± 34	98 ± 30	58 ± 17	40 ± 12
σ, mb $A^{36}(n,\alpha)S^{33*}$:	41 ± 25	22 ± 13	3 ± 3	<3	<5

* Under the auspices of the U. S. Atomic Energy Commission.
[1] E. R. Graves and J. H. Coon, Phys. Rev. **70**, 101 (1946).
[2] Enriched argon kindly supplied by Professor W. W. Watson of Yale University.
[3] Kinsey, Bartholomew, and Walker, Phys. Rev. **85**, 1012 (1952).
[4] G. T. Hunter and H. T. Richards, Phys. Rev. **76**, 1445 (1949).

PA9. Limiting Q Value for $K^{39}(\alpha p)K^{42}$.† J. P. SCHIFFER AND ERNEST POLLARD, *Yale University.*—The limiting Q value for $K^{39}(\alpha p)K^{42}$ has not been measured since 1936.[1] The value given does not check the mass values proposed by Collins, Nier, and Johnson.[2] To see whether in the earlier work the group of maximum energy was actually observed a target of KI was bombarded by 7.8-Mev alpha-particles generated in the cyclotron. At 90° the measured range of protons was 57.7 cm. This corresponds to a Q value of -0.18 Mev. The expected value from mass determinations is -0.28 ± 0.13 Mev. There is thus no discrepancy. The further group structure is clearly complex indicating that between the ground state and 4 Mev of excitation there are several excited states of K^{42}.

† Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] E. Pollard and C. J. Brasefield, Phys. Rev. **50**, 890 (1936).
[2] Collins, Nier, and Johnson, Phys. Rev. **84**, 717 (1951).

PA10. Inelastic Scattering of Protons from Ca^{40}.† C. M. BRAAMS,* C. K. BOCKELMAN, C. P. BROWNE, AND W. W. BUECHNER, *M.I.T.*—Targets of metallic calcium evaporated onto Formvar foils have been bombarded with protons from an electrostatic accelerator, and the proton groups emitted at 90 degrees to the beam have been analyzed with a magnetic spectrograph. Incident proton energies in the region of 7 Mev were used. From an analysis of the target based on protons elastically scattered and from studies made as a function of the bombarding energy, four groups of inelastically scattered protons have been assigned to calcium. These results indicate energy levels in Ca^{40} at 3.35, 3.74, 3.90, and 4.49 Mev. In previous work on this reaction,[1] only a level at 3.8 Mev has been reported.

† This work has been supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission
* Fellow of the Elsevier Foundation, Amsterdam.
[1] J. A. Harvey, Phys. Rev. **88**, 163 (1952).

PA11. (p,n) Thresholds of Nuclei with $49 \leq A \leq 75$. CARROLL C. TRAIL* AND C. H. JOHNSON, *Oak Ridge National Laboratory.*—Seven (p,n) thresholds for nuclei with $49 \leq A \leq 75$ have been measured with the Oak Ridge 2-Mev electrostatic generator. Proton currents of 100 microamperes were incident upon water-cooled targets. Separated isotopes were obtained from the Stable Isotopes Division of Oak Ridge National Laboratory and were evaporated upon gold or platinum blanks. Target thicknesses were approximately 30 kev for 1-Mev protons. Proton energies were analyzed by a 90° bending magnet which was calibrated against $F^{19}(p,\alpha\gamma)$ resonances and the $Li^7(p,n)$ threshold. The (p,n) threshold of Ti^{49} is 1.420 Mev; Mn^{55}, 1.039; Zn^{67}, 1.812; As^{75}, 1.674; each with an uncertainty of 0.005 Mev. The threshold of Zn^{70} is 1.47 Mev; Ga^{71}, 1.04; Ge^{73}, 1.17, each with an uncertainty of 0.03 Mev. An upper limit of 0.65 Mev is placed on the threshold of Ca^{48}.

* Graduate student at Agricultural and Mechanical College of Texas, working under Oak Ridge Institute of Nuclear Studies Fellowship.

PA12. Excitation Function for $Mn^{55}(\gamma,3n)Mn^{52}$.* R. L. HINES, *University of Michigan.*—The x-ray beam from the University of Michigan synchrotron has been used to determine the activation curve of the $Mn^{55}(\gamma,3n)Mn^{52}$ reaction from 30 Mev to 80 Mev by the method of induced radioactivity. Electrolytically pure manganese, in the form of flat strips, and a copper monitor foil are covered with cadmium foil to suppress the slow neutron flux, and exposed to the x-rays. The resulting 21-minute positron activity is measured with a thin wall Geiger counter surrounded by CR anticoincidence counters and shielded with iron. The $Cu^{63}(\gamma,n)Cu^{62}$ reaction is used as a monitor. The cross section curve is computed using the x-ray spectrum differences. The statistical probable error of each point is about 7 percent. The peak in the cross section is at 40 Mev and the width at half-maximum is about 15 Mev. An upper limit can be set for the $Mn^{55}(\gamma,4n)Mn^{51}$ reaction, and competition from it appears to be too small to account for the fall-off of the $(\gamma,3n)$ reaction. The total integrated cross section for the $(\gamma,3n)$ reaction is 1.4 percent of the $Cu^{63}(\gamma,n)$ integrated cross section. This gives an integrated cross section of 0.010 Mev barn and a maximum cross section of 0.8 millibarn. The cross section for γ-absorption at 45 Mev for Mn as estimated from neutron yield measurements is 7 millibarns.

* Supported by the U. S. Atomic Energy Commission.

PA13. A Study of the Thresholds for the Reactions $Cu^{63}(\gamma,n)Cu^{62}$ and $Ag^{109}(\gamma,n)Ag^{108}$. ERICH HARTH, LEO SEREN, MILTON BIRNBAUM, AND RALPH TOBIN, *Naval Research Laboratory.*—The NRL betatron has been used to study the nature of thresholds for photoneutron reactions. The peak energy of the betatron was accurately controlled with a magnetic flux integrator. The thresholds were determined by examining the induced radioactivity as a function of the peak bremsstrahlung energy. Two different methods of analyzing the data were used. In a log-log analysis, activity was plotted against $E_{pb}-E_t$ (where E_{pb} is the peak bremsstrahlung energy and E_t is the threshold energy) for different values of E_t. It was found that a particular value of E_t gave a straight line up to at least 3 Mev above threshold. This criterion can be used as an experimental definition of the threshold. The values of the thresholds obtained from visual inspection of the activation curve agree with those obtained from the log-log analyses, the uncertainty being about 15 kev in each case.

PA14. The (γ,n) Thresholds of Cu^{63} and Ag^{109} Based on the (γ,n) Thresholds of N^{14}, O^{16}, and C^{12}. MILTON BIRNBAUM, ERICH HARTH, LEO SEREN, AND RALPH TOBIN, *Naval Research Laboratory.*—In order to determine the peak bremsstrahlung energies corresponding to different flux integrator (helipot) settings for the NRL betatron, the (γ,n) thresholds of N^{14}, O^{16}, and C^{12} were measured. The energies corresponding to these thresholds are known precisely from mass data. The energy scale thus determined exhibits a nonlinearity in the integrator settings of about 4 percent. The (γ,n) threshold for Cu^{63} was found to be 10.61 ± 0.05 Mev. The (γ,n) threshold for Ag^{109} is 9.07 ± 0.07 Mev. The larger uncertainty in the Ag^{109} threshold is due mainly to the nonlinearity of the scale. The activation curves of N^{14}, O^{16}, and C^{12} in the neighborhood of threshold (up to about 300 kev above threshold) appear to be linear with respect to peak bremsstrahlung energy. This is in contrast to the activation curves for Cu^{63} and Ag^{109}, which are approximately parabolic in the neighborhood of threshold.

PA15. The Effect of Magnetic Flux Amplitude on the Flux Integrator Energy Control of a Betatron. LEO SEREN, MILTON BIRNBAUM, ERICH HARTH, AND RALPH TOBIN, *Naval Research Laboratory.*—In the attempt to achieve precise energy control and stability of the 22-Mev NRL betatron, it was discovered that the bremsstrahlung energy with a particular flux integrator setting is a function of the amplitude of the magnetic flux. This effect can be explained on the assumption of a constant time delay in producing the expander pulse. On this assumption, we have $E_{pb}=E_{fi}+\omega\Delta t(E_{ma}^2-E_{fi}^2)^{\frac{1}{2}}$, where E_{pb} is the peak bremsstrahlung energy produced, E_{fi} is the energy corresponding to the flux integrator setting, E_{ma} is the energy corresponding to the magnet amplitude, ω is the angular frequency, and Δt is the time delay. Small changes in E_{pb} with changes in E_{ma}, at constant E_{fi}, were observed with nuclear threshold detectors. An experimental agreement with the above formula was obtained for Δt equal to 18 microseconds. For precise energy control and reproducibility to 0.1 percent, it is necessary to keep E_{ma} as well as E_{fi} constant. The energy is then computed from the above equation.

FRIDAY AFTERNOON AT 2:15

Wardman Park, Continental Room

(E. M. PURCELL presiding)

Electronic and Nuclear Spins and Moments

Q1. A Method of Measuring the Gyromagnetic Ratio of the Free Electron.* H. R. CRANE, R. W. PIDD, AND W. H. LOUISELL, *University of Michigan.*—It is known that a measurement of the magnetic moment of the free electron by a Stern-Gerlach type experiment violates the uncertainty principle. Several alternative schemes in which it is not violated have been advanced. The only one which has yielded even partial success is the double scattering of electrons on nuclei. Theory predicts partial polarization in the first scattering event, and an asymmetry in scattered intensity in the second. Success to the extent of showing that a polarization exists has been reported, but no experiment has yet yielded a quantitative value of g. We have devised two extensions of the experiment. In the first a magnetic field is interposed between the two scatterers, parallel to the path of the electron. This makes the electron moment precess and rotates the plane of asymmetry in the second scattering event. In the second the electron is trapped in a magnetic field between first and second scatterers, for a large number of "cyclotron" revolutions. This will compare the precession and cyclotron frequencies to such precision that radiative corrections to the moment can be investigated. The field must be nearly uniform to prevent depolarization. The first extension has succeeded and the second is under way.

* Supported by the U. S. Atomic Energy Commission

Q2. An Experimental Measurement of the Gyromagnetic Ratio for the Free Electron.* W. H. LOUISELL, R. W. PIDD, AND H. R. CRANE, *University of Michigan.*—An experiment on the double scattering of 420-kev electrons on nuclei has been performed with the modifications proposed in the preceding abstract. First and second targets are 24 feet apart on the axis of a 30 foot, 6 inch diameter solenoid, producing 93 gauss. The electrons precess through 5 revolutions in flight between the two scatterers. At the second scattering station, two scintillation counters are placed at 78° from the axis of the solenoid and opposite in azimuth. These, with the second scatterer constitute a head which can be rotated about the axis of the solenoid. A measurement through 360° removes effects from inherent differences in the counters, and determines the plane of asymmetry of the scattered electron intensity. Pulse-height discrimination reduces the effects of slow (inelastically scattered) electrons. The first scatterer is gold. Alternately the second is gold and aluminum, of equal scattering power. All other conditions are constant. The polarization asymmetry is obtained from the ratio of the gold and aluminum intensities. This eliminates asymmetries other than polarization. Three measurements, in which the precession was 1770, 1800, and 1830 degrees were made. g obtained was 1.99 ± 0.02. The magnitude of the asymmetry is about $\frac{1}{2}$ that predicted, suggesting some depolarization.

* Supported by the U. S. Atomic Energy Commission.

Q3. On the Measurement of the Gyromagnetic Ratio for the Free Electron: Precession and Depolarization.* K. M. CASE AND H. MENDLOWITZ, *University of Michigan.*—In connection with the foregoing proposal of Crane, Pidd, and Louisell for measuring the gyromagnetic ratio of a free electron, we have investigated the change of polarization of an electron moving in a uniform magnetic field. Using readily constructed Green's functions, a transformation matrix is obtained which gives the electron wave function just prior to the second scattering in terms of that following the first scattering. The result agrees in essentials with semiclassical expectations.

We have also considered the depolarization occurring after a polarized electron beam is injected into a betatron type field. Because of oscillations, the electrons will see a uniform magnetic field in the Z direction to which is added a small parallel oscillating field and a small oscillating field perpendicular to this. Only the latter causes significant depolarization. If the electrons are to make N revolutions before being 50 percent depolarized we find, $N\simeq 1/4n\langle\theta_z^2\rangle_{Av}$, where n is the fall-off index for the magnetic field and $\langle\theta_z^2\rangle_{Av}$ is the mean square angle of injection of the electrons with respect to the median plane. Practical values of n and θ, 0.05 and 1°, allow $\sim 10^4$ revolutions. If, then, the plane of asymmetry is measured to ±30°, g will be obtained to one part in $\sim 10^3$.

* Supported by the U. S. Atomic Energy Commission.

Q4. Spin-Orbit and Spin-Spin Interactions in Molecular Hydrogen. R. G. BARNES, P. J. BRAY, AND N. J. HARRICK, *Harvard University.*—In a forthcoming paper, the authors extract the interaction constants[1] c and d from measurements of the deuterium rotational spectrum ($\Delta m_I=0$, $\Delta m_J=\pm 1$) and find them useful for reducing the dispersion in the values of the diamagnetic interaction[1] term $\xi_{\pm 1}-\xi_0$ and the electron quadrupole moment[1] Q_e as evaluated using c and d from deuterium nuclear spectrum measurements. Consequently, the hydrogen c and d values have been calculated from previously published[2] hydrogen rotational measurements. These are important as checks on the hydrogen nuclear c and d values[3] and do reduce materially the dispersion and possible field dependence of the calculated $\xi_{\pm 1}-\xi_0$ and Q_e values for hydrogen. The hydrogen rotational c and d results (obtained from the 4872.5 and 6607.8-gauss data of Table V of reference 2 and checked by the 3700 and 6700-gauss data of the same table) are $c=113\,960\pm 88$ cps and $d=57\,662\pm 20$ cps. These overlap the intermediate field nuclear values $c=113\,904\pm 30$ cps, and $d=57\,671\pm 24$ cps, and the high field nuclear values $c=113\,846\pm 85$ cps and $d=57\,570\pm 27$ cps. That the new c and d values markedly reduce the possible field dependence of Q_e depicted in reference 2 will be shown.

[1] N. F. Ramsey, Phys. Rev. **85**, 60 (1952).
[2] N. J. Harrick and N. F. Ramsey, Phys. Rev. **88**, 228 (1952).
[3] Harrick, Barnes, Bray, and Ramsey Phys. Rev. (to be published).

Q5. Nuclear Shielding in H_2 and D_2. P. J. BRAY AND R. G. BARNES, *Harvard University.*—The quantity $\sigma_{1,\pm 1}-\sigma_{1,0}$ (where σ_{J,m_J} denotes the nuclear shielding factor for a molecule in the state specified by J and m_J) has been detected in recent molecular beam experiments with H_2 and D_2 as suggested by Ramsey.[1] The accuracy is low but upper bounds are set on the magnitudes. Since the theoretical expression[1] for $\sigma_{1,\pm 1}-\sigma_{1,0}$ involves appropriate averages of $\Sigma_k 3\zeta_k^2-r_k^2/r_k^5$ (where r_k is the radius vector to the kth electron), accurate measurements will allow a test of the wave functions used in evaluating the electron quadrupole moment and the quantity[2] q involved in nuclear quadrupole interactions.

Published measurements[3] and new data yield values ranging from $\sigma_{1,\pm 1}-\sigma_{1,0}=(-1.2\pm 1.6)\times 10^{-4}$ for H_2 nuclear resonances

$(\Delta m_I = \pm 1,\ \Delta m_J = 0)$ at high magnetic fields, to $\sigma_{1,\pm 1} - \sigma_{1,0} = (4.0 \pm 6.0) \times 10^{-6}$ for D_2 rotational resonances $(\Delta m_J = \pm 1,\ \Delta m_I = 0)$ at high magnetic fields. Other measurements will be reported and possible improvements in accuracy by factors of five or more will be discussed. More detailed accounting will be given of the information to be extracted from measurements of this quantity.

[1] N. F. Ramsey, Phys. Rev. **83**, 540 (1951).
[2] Kellog, Rabi, Ramsey, and Zacharias, Phys. Rev. **57**, 677 (1940).
[3] Harrick, Barnes, Bray, and Ramsey, Phys. Rev. (to be published); N. J. Harrick and N. F. Ramsey, Phys. Rev. **88**, 228 (1952)

Q6. Nuclear Resonance Line Structure in HD and Molecular Shielding in HD, H_2, and D_2.* T. F. WIMETT,† *M.I.T.*—Line splitting in both the proton and deuteron magnetic resonances in HD was predicted by Ramsey and Purcell[1] and has been observed by means of the radiofrequency pulse technique[2] and also by a line broadening measurement.[3] We will report a measurement of this splitting by the direct recording of the lines obtained in a nuclear resonance absorption experiment of very high resolution. As measured at 15 kilogauss, the splitting observed was $\delta = 42.7 \pm 0.7$ cycles. By comparing the ratio of proton and deuteron resonance frequencies in HD with that observed in a mixture of H_2 and D_2 gases, the following difference between the molecular shielding factors for H_2 and D_2 was obtained: $\sigma D_2 - \sigma H_2 = (0.65 \pm 0.59) \times 10^{-7}$. The difference in the shielding fields in D_2 and HD was obtained by measuring the shift between the deuteron resonance in D_2 from that in HD using a single sample containing both gases. The following result was found: $\sigma D_2 - \sigma HD = (0.48 \pm 0.32) \times 10^{-7}$.

* This work has been supported in part by the Signal Corps, Air Materiel Command, and the U. S. Office of Naval Research.
† Now at the Los Alamos Scientific Laboratory.
[1] N. F. Ramsey and E. M. Purcell, Phys. Rev. **85**, 143 (1952).
[2] H. Y. Carr and E. M. Purcell, Phys. Rev. **88**, 415 (1952).
[3] Smaller, Yasaitis, Avery, and Hutchinson, Phys. Rev. **88**, 414 (1952).

Q7. Doppler Effects in the Atomic Beam Magnetic Resonance Method. RICHARD T. DALY, JR., AND JERROLD R. ZACHARIAS, *M.I.T.*—Observations have been made on the ground state hfs splitting of Rb^{87} and Cs^{133} atoms. The sharpest line in the rf spectrum, in a weak external field, is that for which $\Delta F = \pm 1,\ \Delta m_F = 0$. It is shown that for atoms passing through a wave guide with a standing wave pattern along the beam path the above resonance is split into two peaks separated by a frequency $2v/\lambda g$, where λg is the guide wavelength in the beam direction, and V is the velocity of the atom. The width of each peak at half intensity is determined by the velocity spread in the beam when the length of the transition region is equal to, or greater than, λg. Curves will be shown for various values of atomic velocity and λg. A value for the atomic ground state hfs splitting in Rb^{87} using the same line in Cs^{133} [$\Delta(Cs^{133}) = 9192.632 \pm 0.002$ Mc/sec] as a standard will be given. A tentative measurement gives $\Delta(Rb^{87}) = 6834.685 \pm 0.002$ Mc/sec.

Q8. The Study of the Hyperfine Structure of Silver with the Aid of a Universal Ionizer for Atomic Beams. GÜNTER WESSEL AND HIN LEW, *National Research Council, Canada.*—A serious limitation in the field of molecular beams has been overcome, at least in part, through the successful application of an electron bombardment ionizer of the Heil type[1] to a beam of atoms in a magnetic resonance apparatus. Despite an ionization efficiency of only 1 part in 10^5, a high signal-to-background ratio has been achieved through the use of a modulated beam and a narrow band amplifier as well as the usual mass spectrometer. The ionizer has been applied to a study of the hfs of silver, an element which cannot be detected by the familiar surface ionization method. The hyperfine separations and g_J of the ground state of both isotopes have been measured and are as follows: $\Delta\nu(Ag^{107}) = 1712.56 \pm 0.04$ Mc/sec, $\Delta\nu(Ag^{109}) = 1976.94 \pm 0.04$ Mc/sec, g_J (both isotopes) $= 2(1.00116 \pm 0.00010)$. The $\Delta\nu$ values confirm the optical measurements of Brix, Kopfermann, Martin, and Walcher.[2] The g value is equal to the anomalous gyromagnetic ratio of the electron within the accuracy of the measurements.

[1] H. Heil, Z. Physik **120**, 212 (1943).
[2] Brix, Kopfermann, Martin, and Walcher, Z. Physik **130**, 88 (1951).

Q9. The Hyperfine Structure of Iodine.* J. G. KING, H. H. STROKE, AND V. JACCARINO, *M.I.T.*—The atomic beam magnetic resonance method has been used to investigate the $^2P_{\frac{3}{2}}$ atomic ground state of the stable isotope of iodine. From observations of the Zeeman frequencies in a known weak magnetic field the value of $5/2\hbar$ for the nuclear spin I has been verified. Further work is in progress to determine the nuclear magnetic dipole and electric quadrupole interaction constants. There has been considerable interest in the hyperfine structure of iodine for some time because of the possible existence of a nuclear magnetic octupole interaction.[1]

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and the Office of Naval Research.
[1] S. Tolansky Proc. Roy. Soc. (London) **A170**, 205 (1939). H. B. G. Casimir and G. Karreman, Physica **9**, 494 (1942).

Q10. Polarization of Nuclei in Metals. ALBERT W. OVERHAUSER, *University of Illinois.*—A new method for producing polarized nuclei is made possible by the spin paramagnetic resonance absorption of conduction electrons in metals. The important interaction between electrons in the conduction band and nuclear spins is the hyperfine structure coupling of an S state, proportional to $\mathbf{I} \cdot \mathbf{s}$, which gives rise to the predominant nuclear relaxation process in metals and contributes to the electron paramagnetic relaxation. If the electron resonance of a metal in a magnetic field is completely saturated, it follows from a *dynamical* study of the relaxation processes that the nuclei will be polarized to the same degree they would be if their gyromagnetic ratio were that of the electron spin. More generally, the degree of polarization can be described by an effective gyromagnetic ratio, $\gamma_{eff} = \gamma_n + s|\gamma_e|$. Here, γ_n and γ_e are the gyromagnetic ratios of the nuclei and electron spins, and s is the fractional saturation multiplied by T/T', where T is the nuclear relaxation time and T' is the nuclear relaxation time produced only by $\mathbf{I} \cdot \mathbf{s}$ interactions. At 2°K and fields of 10^4 oersteds, 50 percent polarization appears possible by present techniques, the major problem being the preparation of sufficiently finely powdered specimens. Some obvious applications are polarized neutron reactions (e.g., on Li), angular dependence of radioactive disintegration, and nuclear resonances resulting from rare isotopes.

Q11. The Quadrupole Moments of the Stable Antimony Nuclei. G. SPRAGUE AND D. H. TOMBOULIAN, *Cornell University.*—An extension of the existing term analysis of the spectrum of Sb II has led to the reliable identification of lines which are known to exhibit well resolved hfs patterns. Among the few such lines which reveal a simple pattern are the three transitions whose wavelengths in angstroms are 5057, 5895, and 6806. Based on the measurements of the hfs separations of these lines, it has been possible to arrive at values of the nuclear electric quadrupole moments of Sb^{121} and Sb^{123} from a study of the splitting of the $5s5p^3\ ^3P_1$, $5p6s\ ^3P_1$, and $5p6p\ ^3D_1$ states. Utilizing the recent value of the quadrupole moment ratio as determined by microwave techniques, corrections have been applied for the perturbing effects of unassigned nearby levels. The present calculations yield the following results for the quadrupole moments of the two isotopes: $q_{121} = -1.3 \times 10^{-24}$ cm^2 and $q_{123} = -1.7 \times 10^{-24}$ cm^2.

FRIDAY AFTERNOON AT 2:15

Shoreham, Main Ballroom

(M. S. LIVINGSTON presiding)

Invited Papers in Nuclear Physics

R1. The Caltech Synchrotron and Some Experiments with High Energy Photons. R. F. BACHER, *California Institute of Technology.* (40 min.)

R2. X-ray Spectrometer for Nuclear Energy Studies with a Betatron. H. W. KOCH, *National Bureau of Standards.* (30 min.)

R3. Analysis of High Energy Nuclear Disintegrations. W. H. BARKAS, *University of California, Berkeley.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Wardman Park, Burgundy Room

(N. M. KROLL presiding)

Invited Paper

RA1. Lattice-Space Quantization of Nonlinear Field Theory. L. I. SCHIFF, *Stanford University.* (30 min.)

Theoretical Physics (Relativity and Field Theory)

RA2. Generalized Canonical Ensemble in Quantum Mechanics.* PETER G. BERGMANN, *Syracuse University.*—In a previous paper[1] it was shown that an ensemble can be constructed so that it is canonical simultaneously with respect to several variables, which need not be time-independent constants of the motion, and that this construction is invariant under the same group with respect to which the assumed law of nature (the chosen Hamiltonian) is invariant. This construction has been transferred to quantum mechanics with the result that partition function and (ensemble) entropy can be constructed even if the several variables with respect to which the ensemble is canonical do not commute with each other. The mean expectation values of these variables are given, as usual, by the negative partial derivatives of the logarithm of the partition function with respect to the "thermodynamic forces."

* Supported by Office of Scientific Research, U. S. Air Force.
[1] P. G. Bergmann, Phys. Rev. **84**, 1026 (1951).

RA3. An Equipartition Principle of Generalized Canonical Ensembles.* HARRY L. FRISCH, *Syracuse University.*—The equipartition of energy of a canonical ensemble has in the past proved fruitful in deriving averages of interesting parameters. It can be shown that an analogous principle holds for a generalized canonical ensemble, i.e., one whose distribution depends on a set of "additive" parameters a_i. With the help of this generalized equipartition principle one can calculate averages of certain functions of the coordinates that may be of interest. At equilibrium the equipartition principle reduces to the classical result, provided that one of the a_i's (or a sum of some of them) is the Hamiltonian of the system.

* Supported by Office of Scientific Research, U. S. Air Force.

RA4. Logical Relations between the Principles of Statistical Mechanics and Thermodynamics.* J. S. THOMSEN, *The Johns Hopkins University.*—Logical relations of necessity sufficiency are established between the following propositions of the thermodynamics and statistical mechanics: microscopic reversibility, detailed balance, the ergodic hypothesis, the Second Law, and a condition on the transition probability matrix λ_{ij} which will be called the "λ-hypothesis." (Microscopic reversibility and detailed balance are used with meanings which will be defined in this paper and which differ somewhat from those frequently employed.) In particular, it can be shown that microscopic reversibility implies the Second Law but that the converse does not hold.

* A part of a doctral dissertation in The Johns Hopkins University, Department of Physics.

RA5. Rigid Motion in Special Relativity. G. SALZMAN AND A. H. TAUB, *University of Illinois.*—A rarefied body of ideal gas, which is subject to no external forces and which has small energy density, may be thought of as moving in a Galilean space-time R_4 according to the five equations $(\rho u^\alpha)_{;\alpha}=0$ and $T^{\alpha\beta}{}_{;\beta}=0$, where ρ is the rest density of the gas, u^α its normalized average four-velocity vector field, and the stress-energy tensor is $T^{\alpha\beta}=(\rho c^2+\rho\epsilon+p)u^\alpha u^\beta+pg^{\alpha\beta}$, where ϵ is the internal energy per unit rest mass and p is the hydrostatic pressure. Solutions of these equations have been obtained in which u^α is the velocity field of any one of those Born-type rigid motions in which the streamlines are segments of path curves of a nontrivial one-parameter group of Lorentz transformations of R_4 into itself. It was further assumed that $\epsilon=p/[\rho(\gamma-1)]$ and that the specific entropy of the gas was constant on a space-like hypersurface which intersects each of the streamlines, the initial hypersurface. It has therefore been shown that a gas can move in accordance with Born's definition of a rigid body motion in special relativity.

RA6. Intrinsic Magnetic Moment of Particle of Spin ½. F. J. BELINFANTE, *Purdue University.*—The equations of Fierz-Pauli's theory of spin-½ particles[1] have been rewritten in a way resembling Dirac's electron theory. Manifest covariance has purposely been sacrificed for obtaining complete reduction of the representation of the spatial rotation and reflection group by the field. This simplifies the discussion of Fierz-Pauli's "subsidiary equations."[1] Also expression of the "derived variables" in terms of the eight main field compo-

nents (forming the spin-$\frac{1}{2}$ representation of the spatial group) is eased by dropping covariant formulation of the (anyhow covariant) theory. In interaction with electromagnetic fields the particle is found to possess a magnetic moment proportional to its spin. The gyromagnetic ratio is $(q/3mc)$, where q is the charge. This ratio is $(q/2mc)$ for vector mesons and (q/mc) for Dirac particles, suggesting magnetic moment $(qh/2mc)$ for all "bare" elementary particles with any spin $\neq 0$. This result invalidates Sugawara's theory of the anomalous magnetic moments of nucleons,[2] in which to nucleons virtually excited to spin-$\frac{1}{2}$ states of charge $q=2e$ a magnetic moment $6(eh/2Mc)$ instead of $2(eh/2Mc)$ was assigned.

[1] M. Fierz and W. Pauli, Proc. Roy. Soc. (London) **A173**, 211 (1939).
[2] M. Sugawara, Progr. Theoret. Phys. (Japan) **8**, 549 (1952).

RA7. Quantum Electrodynamics in a Space of Constant Curvature. MARTIN GUTZWILLER, *University of Kansas* (introduced by M. Dresden).—An attempt has been made to investigate whether any convergence properties are altered by the use of a curved space. To obtain a curved space theory, which allows the definition of linear and angular momentum, a Riemannian space allowing a 10-parameter group of motions was examined. Such a space has a constant curvature. The requirement of three space like and one time like dimension allows but two realizations. One of these, a one sheeted hyperboloid of revolution has been investigated. It is possible to construct a theory of spin $\frac{1}{2}$ particles, described by spinors. The equation satisfied by these spinors is unique if each component satisfies the Gordon-Klein equation (in this space) and if a continuity equation is demanded. The solution of these field-free equations yield discrete linear and angular momenta. If one goes to the limit of zero curvature the theory goes over into the Dirac theory. One may treat the free electromagnetic field in the same fashion. It is possible to cast the theory in a Lagrangian form.[1] Then one can discuss the second quantization as well as the Coulomb problem.

[1] See W. Pauli, Ann. Physik **18**, 337 (1933).

RA8. The True Vacuum and the Dressed Particles in Quantum Field Theory.* BRUNO ZUMINO, *New York University*.—An operator is defined which generalizes the Bloch-Nordsieck transformation and permits a correct definition of the true vacuum and the true particle states in field theory. The operator is similar to those defined in various ways by other authors.[1] The different characterizations are shown to be essentially equivalent. A perturbation procedure taking into account the possibility of bound states is outlined. Creation and destruction operators for the "dressed particles" as well as for bound particles are introduced and their properties are discussed. Renormalization is necessary to ensure the consistency of the above procedure, also if convergence should not follow. The various renormalization conditions used in the literature can be shown to be equivalent to the one used here.

* Supported by the U. S. Office of Naval Research.
[1] B. Ferretti, Nuovo cimento **7** (1950), various notes; **8**, 108 (1951). Heitler and Ma, Phil. Mag. **40**, 651 (1949). F. J. Dyson, Proc. Roy. Soc. (London) **A207**, 395 (1951); Phys. Rev. **83**, 1207 (1951). M. Gell-Mann and F. Low, Phys. Rev. **84**, 350 (1951).

RA9. Electromagnetic Mass in Darling's Theory of the Elementary Particles. HANS FREISTADT, *Newark College of Engineering*.—On the basis of an unpublished paper of Schrödinger,[1] the author had previously suggested[2] that in Darling's Theory of the Elementary Particles[3] a free charged particle might be represented by world-symmetric solutions of the Klein-Gordon equation of the form $H_1(ks)/(ks)$ (see reference 1) and $H_1(ks)/(ks)$ (see reference 2) [$H_1(x)$ (see reference 1) is the Hankel function of the first kind of order 1, s is the relativistic interval, k is the Compton wave number]. There would then be a purely classical interaction energy of the form $\bar{j}^{\alpha}A_{\alpha}$ between the particle and its own electromagnetic field, which might yield an electromagnetic correction to the mass spectrum obtained in Darling's theory.[4] It was found impossible to obtain in this manner a correction which agrees with the empirical correction used by the author[5] to fit experimental results. Indications are that the situation would not be improved by using solutions of the Dirac equation.

[1] E. Schrödinger, Princeton Lectures, 1934.
[2] Colloquium of the Dublin Institute for Advanced Studies, 1951.
[3] B. T. Darling, Phys. Rev. **80**, 460 (1950).
[4] P. R. Zilsel, Phys. Rev. **82**, 557 (1951).
[5] Hans Freistadt, Compt. rend. **235**, 23 (1952); Phys. Rev. **87**, 198 (1952).

RA10. Relativistic Two-Body Equation. BEHRAM KURŞUNOĞLU, *Cornell University*.*—The Bethe-Salpeter equation for two bound spin $\frac{1}{2}$ particles presents some formal difficulties as regards its physical interpretation. Among these are the existence of "spurious" plane wave solutions in the absence of interaction, and also the precise meaning of a wave function depending on two different times cannot be understood from the equation itself. By a linear transformation of the wave function $\chi(12)$ one can easily obtain from the Bethe-Salpeter equation an equation of a familiar form,

$$(\gamma^A\partial_A+\kappa)\psi(A)=-\int\zeta_{12}(AA')\psi(A')dA',$$

where $A=1$, 2 and $\gamma_\mu{}^A$ satisfy

$$\gamma_\mu{}^A\gamma_\nu{}^B+(-1)^{A+B}\gamma_\nu{}^B\gamma_\mu{}^A=2\delta_{AB}\delta_{\mu\nu},\qquad \gamma^A\partial_A=\gamma_\mu{}^1\partial_{1\mu}+\gamma_\mu{}^2\partial_{2\mu},$$
$$\kappa=\kappa_1+\kappa_2,\qquad dA'=d1'd2'$$

and ζ_{12} is the transformed interaction operator. For a complete solution of the two-body problem there is also the need for an integral equation for ζ_{12}. Other properties of the above equation will be discussed at the meeting.

* Research supported by the Turkish Government and the U. S. Office of Naval Research.

RA11. Approximate Two-Body Relativistic Wave Equations, Part II. Z. V. CHRAPLYVY, *Saint Louis University*.—In the extension of the Foldy-Wouthuysen method to two-particle equations given[1] in Part I, the Hamiltonian was transformed into an even-even operator, which made it possible to split $\kappa\psi=E\psi$ into four quadruples of equations, each involving only four components of ψ, and then to select the quadruple describing states of both particles possessing positive energy. However, the transformation was designed only for systems of particles of different masses. Now it is shown that the requirement of an even-even Hamiltonian was too stringent and that to separate out the appropriate quadruple of equations it is sufficient to make the Hamiltonian "partially even." The most general canonical transformation effecting this is given. It contains that of Part I as a special case but may be applied to equal-mass systems as well. Under the generalized scheme there is some arbitrariness in the procedure (choice of the transformation), but the result (the reduced four-component wave equation) is unique.

[1] Z. V. Chraplyvy, Phys. Rev. **89**, 912 (1953).

RA12. Some Modified Random Walk Problems. M. DRESDEN AND DONALD DRAWBAUGH, *University of Kansas*.—It is frequently possible to represent some of the pertinent physical features of a nonstationary process by an appropriate random walk type process. In an attempt to obtain such a description for the behavior of positrons in metals two modifications of the customary random walk were necessary. (1) One has to allow the possibility of a delay, i.e., one gives the probabilities of the various jumps p_i in a time interval τ, however, $\Sigma p_i=1-d$; here d is the probability of a delay. This problem can be solved using the conventional generator function techniques, as is perhaps apparent from the fact that in the Smoluchowski equation there is only one additional term,

$dP(m|N)$. (2) One has to allow the possibility of the particle (positron) disappearing altogether, i.e., one gives the probabilities of the various jumps p_i in a time τ, but now $\Sigma p_i = 1-a$; a is the annihilation probability. The matrix and generator function methods[1] appear not directly applicable to this problem. One can, using simple arguments, still find the conditional probability function $P(0|m, N)$ as well as the physically more interesting average lifetime of a particle.

[1] M. Kac, Am. Math. Monthly **54**, 369 (1947).

RA13. Initial Conditions in the Expanding Universe and Element Synthesis.* R. A. ALPHER, J. W. FOLLIN, JR., AND R. C. HERMAN, *Applied Physics Laboratory, Johns Hopkins University.*—In the neutron-capture theory of element formation[1] the ylem is a trace of matter (neutrons) in an expanding radiation universe. By the time nuclear synthesis completed with dissociative processes in the cooling universe ($kT \sim 0.1$ Mev), free neutron decay would have given a proton-neutron ratio $R \cong 1/7$. Hayashi[2] has studied this ratio on the basis of nonequilibrium reactions among elementary particles in the epoch prior to element formation and finds $R \cong 4$. The authors have re-examined the above problem with a cosmological model including matter-radiation interconversion, relativistic quantum statistics, and the more recent value for neutron half-life. Depending on neutrino-antineutrino distinguishability and neutron half-life probable error, one finds $\sim 4.5 \leqq R \leqq \sim 6.0$ by the time free neutron decay is dominant. The minimum H/He abundance ratio corresponding to these values of R lies between $\sim 7:1$ and $\sim 10:1$. The effect of $R > 1$ on the theoretical representation of the cosmic abundance data and on the problem of synthesizing nuclei past the gap at atomic weight 5 is being studied.

* This work supported by the U. S. Navy Bureau of Ordnance.

[1] R. A. Alpher and R. C. Herman, *Annual Reviews of Nuclear Science*, Vol. II (Annual Reviews, Inc., Stanford, California, 1953).

[2] C. Hayashi, Progr. Theoret. Phys. **5**, 224 (1950).

RA14. Green's Functions in *S*-Matrix Theory. JAMES L. ANDERSON, *Department of Physics, Rutgers University.*—By making use of some simple ideas borrowed from the theory of functionals, one can represent the various matrix elements of the S matrix of quantum electrodynamics in terms of its vacuum expectation value. More specifically, one considers S_{vac} as a functional of the Feynman propagation functions $S_{\alpha\beta}^F(x-x')$ and $D^F(x-x')$ rather than as a number. Functional differentiation of S_{vac} with respect to $S_{\alpha\beta}^F$, for instance, gives the coefficient of the normal product $N[\bar{\psi}_\alpha(x), \psi_\beta(x')]$ in the series expansion of S. It is also possible to represent in a similar manner the Green's functions introduced by Schwinger[1] and to obtain the integro-differential equations which they satisfy. One result of this analysis is the representation of the mass operator, the polarization operator, and the interaction operator in terms of S_{vac}. It therefore appears likely that a renormalization program could be based on an analysis of the single quantity S_{vac}.

[1] J. Schwinger, Proc. Natl. Acad. Sci. **37**, 452 (1951).

FRIDAY EVENING AT 7:00

Shoreham, Terrace Room

(ENRICO FERMI presiding)

Banquet of the American Physical Society

After-dinner speakers: A. V. ASTIN and L. V. BERKNER

SATURDAY MORNING AT 9:30

Shoreham, Terrace Room

(L. M. LEDERMAN presiding)

Mesons, II. (Including Some Meson Theory)

S1. Pions and Protons from a Target Bombarded by 2.3-Bev Protons in the "Cosmotron."* W. B. FOWLER, R. P. SHUTT, A. M. THORNDIKE, AND W. L. WHITTEMORE, *Brookhaven National Laboratory.*—Preliminary measurements of sign and momentum of particles emitted from a target composed of Be and Al at 57° in the laboratory system to the 2.3-Bev circulating proton beam of the Brookhaven Cosmotron have been made using a 16-inch diameter diffusion cloud chamber with magnetic field of 11000 gauss. About 90 percent of the particles with momentum greater than 200 Mev/c are positive. They have a broad momentum distribution with a maximum somewhat below 900 Mev/c, which is the momentum expected for a proton scattered elastically at 57° by another nucleon. The negative particles, presumed to be mesons, have a momentum distribution extending to 900 Mev/c, with a maximum at about 350 Mev/c. For momenta below 550 Mev/c protons can be distinguished from other positive tracks by an estimate of the density of ionization. If the light positive tracks with momenta from 200 to 550 Mev/c are considered to be mesons, the positive to negative ratio is 1.8 ± 0.5 for the mesons. If the momentum distributions of positive and negative mesons have the same shape, 85 percent of all the positive particles are protons, and the momentum distribution of the protons alone has somewhat fewer low momentum cases than that of all positive particles.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

S2. High Energy Pairs of Particles from Nuclear Interactions. MARCEL SCHEIN, JOSEPH FAINBERG, D. M. HASKIN, AND R. G. GLASSER, *University of Chicago.*—Nuclear plates were exposed to negative pion beams of the 450-Mev Chicago cyclotron to search for high energy pairs produced in nuclear collisions. The pairs found exhibit the following characteristics:

(a) the mass of the particles is less than 10 electron masses, so the pairs probably consist of electrons; (b) the energies of the pairs range from 22 to 205 Mev; (c) the angles between the particles of the pair range from 0.3° to 25.9°; (d) the distance from the star to the point of origin of the pair—"gap"—was definitely less than 2 microns (determined by reprojection); (e) the angle between the center of mass of the pair and the direction of the incoming pion was 125° with a spread of ±15°. The most reasonable assumption seems that they are due to the process: $\pi^0 \rightarrow e^+ + e^- + \gamma$ first discussed by Dalitz.* If this explanation should hold, then from the measured gaps the lifetime must be less than 4×10^{-16} sec. However, if all the seven pairs were due to the proposed decay scheme of the π^0 meson, the probability of the observed angular distribution (e) is certainly less than 2×10^{-4}.

* R. H. Dalitz, Proc. Phys. Soc. (London) **A64**, 667 (1951); See also discussion in Proceedings of The Third Annual Rochester Conference On High Energy Physics, pp. 171–180 (1952).

S3. Production of Copper Radioactivity in the Interaction of Negative Pions and Muons with Zinc. SI-CHANG FUNG AND A. TURKEVICH, *University of Chicago.*—Zinc, in the form of zinc chloride, has been exposed to the magnetically analyzed and collimated 122-Mev π^- beam of the University of Chicago synchrocyclotron. The copper radioactivity formed as a function of depth of penetration of the beam has been determined radiochemically. It is a maximum at the range of the pions. Under our conditions of irradiation and time for chemistry, the copper activity consists of Cu^{61}, Cu^{64}, and Cu^{67}. A second maximum appears, beyond the range of the pions, in the production of Cu^{64} and Cu^{67}, but not of Cu^{61}. The second maximum is interpreted as due to the negative muons in the beam. Absorption data with counters[1] indicate that the original pion beam has in it several percent muons of the same momentum as the pions, and therefore larger range. Preliminary analysis of the data indicates that the slow π^- absorption by zinc giving rise to copper is accompanied by the emission of fewer neutrons (~3) than are found when a proton is also emitted (~5 to 6).[2] The negative muon interaction with zinc appears to lead predominantly to the ejection of one or two neutrons.

[1] R. L. Martin (private communication).
[2] T. T. Sugihara and W. F. Libby, Phys. Rev. **88**, 587 (1952). A. Turkevich and James B. Niday, Bull. Am. Phys. Soc. **28**, No. 2, 13 (1953). Lester Winsberg, Bull. Am. Phys. Soc. **28**, No. 2, 14 (1953).

S4. Interaction Cross Section of μ-Mesons with Nuclei. H. C. WILKINS AND M. ANNIS, *Washington University.**—A measurement has been made of the product $\sigma\bar{m}$, for relativistic cosmic-ray μ-mesons incident on Fe nuclei. $\sigma\bar{m} = (9\pm1)\times10^{-27}$ cm²/nucleus, where σ is the cross section (per nucleus) for a μ-meson-nucleus interaction in which one or more slow neutrons ($E_{neutron} \lesssim 10$ Mev) are produced, and $\bar{m}$ is the mean multiplicity with which slow neutrons are produced in these interactions. The experiment was performed at a depth of 2000 g cm^{-2} below sea level, and the arrangement of G-M counters and neutron counters has been described previously. The new feature of this experiment is that it was found possible, by means of an auxiliary experiment, to account for the nuclear interaction of γ-rays produced locally. With our geometry, this γ-ray effect was not large. The major part of our surprisingly large $\sigma\bar{m}$ can be explained in the following way: The electromagnetic field of the μ-meson is represented as a spectrum of virtual γ-rays whose energies vary from several Mev to several Bev. These virtual γ-rays then interact photoelectrically with the nucleus to produce the observed neutrons. The interactions of the virtual γ-rays below about 300-Mev result mainly in low energy stars which would not have been detected in previous photoplate and cloud-chamber experiments.

* Supported in part by the U. S. Office of Naval Research.

S5. Nuclear Forces from Extended Sources. E. M. HENLEY* AND M. A. RUDERMAN,† *Columbia University.*—Chew[1] has recently proposed a model to describe the very large p-wave phase shifts in meson-nucleon scattering. He assumes a weak and extended gradient coupling. With this model the adiabatic force between two nucleons has been calculated. Terms in the potential include only the exchange of one and two mesons between different nucleons, but include an indefinite number of interactions between a meson and one nucleon, as in the scattering calculation. These terms involve the meson-nucleon scattering matrix far off the energy shell. Comparison will be made with the low energy n-p and p-p parameters.

* Frank B. Jewett fellow.
† National Science Foundation post-doctoral fellow, on leave from the University of California.
[1] G. F. Chew, Phys. Rev. **89**, 591 (1953).

S6. μ-Mesic Atom. L. N. COOPER AND E. M. HENLEY,* *Columbia University.*—An attempt is made to interpret recent experiments performed by Fitch and Rainwater on the gamma-ray spectrum of μ^- mesons which make $2P_{\frac{3}{2}}$ and $2P_{\frac{1}{2}}$ to $1S_{\frac{1}{2}}$ radiative transitions when stopped in matter. For heavy nuclei the probable experimental values for this transition were found to be consistently larger than the values calculated, along the lines suggested by Wheeler, for a nuclear radius as large as $1.35\times A^{\frac{1}{3}}\times10^{-13}$ cm. The nucleus was considered as a uniform sphere of charge and the meson mass was taken to be $210\pm6M_e$. Effects of nuclear polarization, quadrupole moment, screening by atomic electrons, and a meson-nucleon interaction of the order indicated by the charge exchange capture reaction were all too small to account for the difference. An anomalous meson-nucleon interaction, derived from high energy scattering results, though probably overestimated, leads to approximate agreement. By changing the charge distribution alone, experimental results for bismuth, lead, copper, and aluminum can be made consistent with calculations for a uniformly charged sphere of radius of approximately $1.2\times10^{-13}A^{\frac{1}{3}}$ cm. There is previous evidence of such a small Coulomb radius from high energy electron and proton scattering and mirror nuclei, where the radius is reduced by about 10 percent when an exchange term is included.

* Frank B. Jewett fellow.

S7. Photoproduction of Mesons in Deuterium. J. CHAPPELEAR AND K. A. BRUECKNER, *Indiana University.*—By formal algebraic methods an exact solution to the problem of charged and neutral photoproduction in deuterium has been constructed. From the solution in this form the corrections to the usual impulse approximations are easily obtained. It is found that the cross section obtained in this way is modified principally by the presence of terms describing the multiple scattering of the photo produced mesons. The theorem of Lippman and Schwinger, which relates the imaginary part of the forward amplitude to the total cross section, can be used to obtain simple expressions for the total cross section. Preliminary numerical calculations show that when the phase shifts of the multiply scattered mesons are not small, the cross section is considerably altered.

S8. Negative Mu-Meson Nuclear Capture in Hydrogen and Deuterium. H. PRIMAKOFF, *Washington University.**—Theoretical expressions are obtained for the nuclear capture rates of slowed down negative mu-mesons in hydrogen and in deuterium. The ratio of the capture rates depends sensitively on the ratio, r, of the magnitude of spin dependent to spin independent coupling in the mu-meson nucleon interaction. Possibilities of experimental measurement of the capture rate ratio and consequently of determination of r, will be discussed.

* Assisted by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.

S9. A Phenomenological Study of Meson-Nucleon Scattering. S. GASIOROWICZ, *University of California, Berkeley.*—A re-examination of Brueckner's analysis of meson-nucleon scattering, based on the existence of a nucleon isobar, has been carried out with the following changes: The S and P scattering, other than that through the $I=J=\frac{3}{2}$ state, has been treated as arising from terms $(g^2/2M)\int\phi_a\bar{\psi}\gamma_5\psi d^3x$ (treated exactly in an extended source approximation) and $(f/M)\int\bar{\psi}\gamma_5\tau_a\psi\cdot\partial_\mu\phi_a d^3x$; the importance of these terms is suggested by a unitary transformation of the relativistic pseudoscalar interaction term. The isobaric $I=J=\frac{3}{2}$ state has been treated by a modified resonance formalism based on the Klein-Gordon equation. A reasonable fit of the Chicago scattering data is obtained by a proper choice of g and f (treated here as arbitrary constants), with $a=0.30\hbar/\mu c$ and $E=170$ Mev taken as the size of the extended source and the isobar resonance energy, respectively. A feature of the use of the Klein-Gordon equation is the sharpening of the resonance, caused by the appearance of the square of the energy in the resonance denominator. The influence of this modification on the photomeson production excitation function is being studied.

S10. The Capture of μ-Mesons in Matter. F. T. COLE* AND H. A. BETHE, *Cornell University.*—The probability of μ-meson capture by a nucleus has been calculated using an α-particle model of the nucleus. In this model, a μ-meson is captured from the lowest Bohr orbit by a proton embedded in an α-particle subunit of the nucleus, transforming this subunit into a triton and a neutron free with respect to the triton. The excitation energy given to the nucleus is identified with the kinetic energy of the emitted neutron. Approximate wave functions for the α-particle and triton are developed in momentum space by a method of Salpeter.[1] The result for the excitation energy curve differs from previous calculations[2] in having a long "tail" at high excitation energies. The mean excitation energy is 24 Mev, in contrast with 10–15 Mev of the previous work. This higher excitation energy would lead to emission of charged particles, as observed experimentally.[3] The multiplicity of neutrons emitted per μ-meson captured is calculated for some nuclei by the usual evaporation theory, giving the results from 0 to 40 percent higher than experiment, according to the assumptions about neutron binding energy.

* Now at the State University of Iowa.
[1] E. E. Salpeter, Phys. Rev. **84**, 1226 (1951).
[2] J. Tiomno and J. A. Wheeler, Revs. Modern Phys. **21**, 153 (1949); J. M. Kennedy, Phys. Rev. **87**, 953 (1952).
[3] H. Morinaga and W. F. Fry, Phys. Rev. **87**, 182(A) (1952).

Invited Papers

S11. Nuclear Capture of Negative Mu-Mesons in Photographic Emulsions. W. F. FRY, *University of Wisconsin.* (30 min.)

S12. Nuclear Emulsions in High Energy Physics. M. M. SHAPIRO, *Naval Research Laboratory.* (30 min.)

SATURDAY MORNING AT 10:30

Wardman Park, Continental Room

(W. V. HOUSTON presiding)

Invited Papers in Cryogenics

SA1. Recent Experiments on Second Sound in Liquid Helium II. J. R. PELLAM, *National Bureau of Standards.* (30 min.)

SA2. Thermal Conductivity of Supra-Conducting Metals. R. T. WEBBER, *Naval Research Laboratory.* (30 min.)

SATURDAY MORNING AT 9:30

Shoreham, Main Ballroom

(K. WAY presiding)

Nuclear Masses and Fundamental Constants

T1. Present Status of the Mass Synchrometer.* LINCOLN G. SMITH, *Brookhaven National Laboratory* AND C. C. DAMM, *Picatinny Arsenal.*—In the mass synchrometer[1] as presently arranged only those ions can reach the detector (placed radially inside the source) which, on each of three successive passages through the short rf field 180° from the source, receive the same deceleration. These are ions which make a complete rotation in the magnetic field in very nearly an integral number (n) of rf cycles. A sharp peak for each value of n and each ion species is observed on an oscilloscope when a saw tooth sweep is applied to the radiofrequency (f). A wide band electrometer amplifier allows a single peak to be displayed without distortion 30 times/sec. For $n\sim150$, half-width resolutions between 10 000 and 17 000 for masses between 16 and 44 and of about 7500 for mass 130 and peak currents up to 2×10^{-11} amp have been observed. The relative difference in frequency and hence in mass between two components of a doublet is measured by displacing f on alternate sweeps an amount so adjusted that the two peaks appear entirely coincident. This technique has been so refined that the spacing

of two smooth congruent peaks can be determined in one setting to nearly 10^{-3} times the half-width of each.

* Research done at Brookhaven National Laboratory under contract with the U. S. Atomic Energy Commission.
[1] See references given in reference 1 of the following paper.

T2. Doublet Measurements with the Mass Synchrometer.* C. C. DAMM, *Picatinny Arsenal* AND LINCOLN G. SMITH, *Brookhaven National Laboratory.*—To date the following doublets have been measured (in units of 10^{-4} m.u.) with the mass synchrometer:[1] (1) $N_2-CO=112.372\pm0.021$; (2) $C_2H_4-N_2=251.493\pm0.041$; (3) $C_2H_4-CO=363.877\pm0.041$; (4) $C_2H_6-NO=489.623\pm0.055$; (5) $CH_3OH-O_2=363.748\pm0.038$; (6) $C_3H_8-CO_2=727.752\pm0.082$. All isotopes are the ordinary ones. Each value is the mean of from 10 to 21 measurements under varying conditions for harmonics between the 145th and 165th of the cyclotron frequency. Each error is the probable error of a single measurement. Values obtained from nuclear disintegration studies agree within their probable errors with all of ours, while most of those obtained in other recent mass spectrometric work do not.[2] The self-consistency of our measurements is excellent except that (5) is lower than (3) or ½ (6) or (1) plus (2) by about 3 probable errors. Possible reasons for this discrepancy are being studied and will be discussed as will possible sources of systematic error. It is expected that further measurements will be presented.

[1] For first four measurements see Phys. Rev. (to be published).
[2] See C. W. Li, Phys. Rev. **88**, 1038 (1952) and references cited there. See also K. Ogata and H. Matsuda, Phys. Rev. **89**, 27 (1953).
* Research done at Brookhaven National Laboratory under contract with the U. S. Atomic Energy Commission.

T3. A Second Minimum in the Packing Fraction Curve at 50 Neutrons.* T. L. COLLINS, W. H. JOHNSON, JR., AND A. O. NIER, *University of Minnesota.*—Measurements of masses for stable nuclei from S^{32} to Zn^{70} and from Pd^{102} to Xe^{136} have been reported previously.[1,2] Our measurements in the intervening region are now sufficiently complete to allow an examination of stable masses in the neighborhood of the nuclear shell at 50 neutrons. The effect is large, and any mass or binding energy curve shows it clearly. One of the most direct visual presentations of the data is a packing fraction curve, that is $(M-A)/A$ against A. A definite pattern in the scattered points is emphasized first, by joining stable odd A nuclei by a continuous line and second, by drawing a separate curve through the stable even A isotopes for each element (even Z). The latter isotopic curves are smooth. The mass pattern thus displayed shows several features which can be associated with nuclear shell structure. Most striking is the appearance of a definite second minimum in the packing fraction curve at 50 neutron nuclei. To smooth out this dip one would have to reduce the binding energy of, say, Y^{89} about 5 Mev.

* Research supported by joint program of the Office of Naval Research and the Atomic Energy Commission.
[1] Collins, Nier, and Johnson, Phys. Rev. **86**, 408 (1952).
[2] R. E. Halsted, Phys. Rev. **88**, 666 (1952).

T4. Present Status of the Fundamental Atomic Constants. J. A. BEARDEN, M. D. EARLE, J. M. MINKOWSKI, AND J. S. THOMSEN, *Johns Hopkins University.*—The fundamental atomic constants have recently been evaluated in independent studies by Bearden and Watts[1] and Dumond and Cohen.[2] A new investigation has been made by the present authors to determine whether a readjustment of these constants appears necessary. Certain experimental errors have been re-evaluated and some new experimental data have been used. The value of the fine structure constant computed by Salpeter and Newcomb,[3,4] using the hyperfine structure measurement of Kusch and Prodell,[5] is found to be in serious conflict with that implied by the other data considered. Details of this conflict and the present status of the constants will be discussed.

[1] J. A. Bearden and H. M. Watts, Phys. Rev. **81**, 73, 160 (1951).
[2] J. W. M. Dumond and E. R. Cohen, Phys. Rev. **82**, 555 (1951); Am. Scientist **40**, 447 (1952).
[3] E. E. Salpeter and W. A. Newcomb, Phys. Rev. **87**, 150 (1952).
[4] E. E. Salpeter, private communication.
[5] P. Kusch and A. G. Prodell, Phys. Rev. **79**, 1009 (1950).

T5. Nuclear Masses as Rational Multiples of the Electron Mass. ENOS E. WITMER, *University of Pennsylvania.*—The rest mass of any nucleus in any state or of any elementary particle may be written as Mm, where m is the rest mass of the electron. We believe that M is always a rational number.[1] The table here gives the M values for some nuclei in the ground state. The agreement with the experimental data is remarkable.

Nucleus	M in Ground State
n	1838–5/8
H^1	1836–1/11
H^2	3670–4/11
H^3	5496–3/4
He^3	5495–5/7
He^4	7294–1/13
Li^6	10961–4/7
Li^7	12786
Be_8	14588–7/20
Be^9	16423–5/7

There are six nuclei with $Z\leq 8$ for which M is an integer.

[1] E. E. Witmer, Phys. Rev. **87**, 237 (1952).

T6. Comparison of Nuclear and Gamma-Ray Absolute Energy Scales.* K. W. JONES, M. T. MCELLISTREM, R. A. DOUGLAS, AND H. T. RICHARDS, *University of Wisconsin.*—The energy of the 1.37-Mev state of Mg^{24} has been used as a means of comparing nuclear and gamma-ray absolute energy scales. Previous measurements by Lind and Hedgran[1] give a value of 2.2767 ± 0.0003 for the H_ρ ratio of externally converted electrons from the Na^{24} and Au^{198} gamma-rays. Our present measurements used electrostatic analysis to give the ratio of the proton energy for the $Li^7(p, n)Be^7$ threshold to the energy of the Mg^{24} level as measured by inelastic proton scattering. Nine different determinations give a preliminary value of 1.3737 ± 0.0005 for this ratio. If the most recent value of the California Institute of Technology absolute measurement of the Au^{198} gamma-ray is adopted, then a value of 1.8816 ±0.0010 Mev is implied for the $Li^7(p, n)Be^7$ threshold. This value is in agreement with the direct absolute voltage measurements of Herb, Snowdon, and Sala (1.8822 ± 0.0019 Mev) and of Shoupp, Jennings, and Jones (1.8812 ± 0.0019 Mev). It also agrees with Sturm and Johnson's value of 1.8813 ± 0.0007 Mev which is based upon Brigg's absolute measurement of the RaC′ alpha-energy.

* Work supported in part by the Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] D. Lind and A. Hedgran, Arkiv Fysik **5**, 40, 181 (1952).

Post-Deadline Papers, if Any

SATURDAY MORNING AT 9:30

Wardman Park, Burgundy Room

(J. M. CORK presiding)

Beta- and Gamma-Emitters, I

U1. Method for the Determination of the Maximum Energy of Weak Beta-Emitters.* M. FORRO, *Barat College.*—The method is based on the observation that the absorption curve of beta-emitters in gold is a fairly straight line on a semi-logarithmic plotting if measured with a coincidence equipment. It was found that the maximum energy of the beta-spectrum can be represented by the formula

$$E=95\left(\frac{x_2-x_1}{\ln J_1/J_2}\right)^4-0.03,$$

where E denotes the energy in Mev, x_1 and x_2 the thickness of the gold absorbers in g/cm², and J_1 and J_2 the measured intensities at the two absorber thickness. The method is useful in cases where the weakness of the source, or its short lifetime, excludes other methods. The geometrical and other limitations will be discussed.

* Supported by the Research Corporation.

U2. Upper Limit on the Fraction of Positive Particles Emanating from Two β^--Emitters.* G. W. MCCLURE, *Bartol Research Foundation.*—Several investigators[1] have reported cloud-chamber and β-ray spectrograph[2] observations of a small fraction of positively charged particles emanating from β^--emitters. This matter has been further investigated with a small spectrograph (radius of curvature 1.35 cm) designed with particular attention to the reduction of background counts. Although time has not yet allowed a thorough investigation of the positive spectrum from any material, it has been found that the ratio N^+/N^- for particles of $H_\rho=1600$ is less than 10^{-4} for P^{32} and RaE. This ratio is approximately one hundred times smaller than that reported by Groetzinger and Kahn[2] for P^{32} emanations of the same H_ρ value. A detailed investigation of P^{32} will be conducted in order to detect possible fine structure in the positive spectrum.

* Supported by the joint program of the Office of Naval Research and the Atomic Energy Commission.
[1] For bibliography see G. Groetzinger and F. Ribe, Phys. Rev. **87**, 1003 (1952).
[2] G. Groetzinger and D. Kahn, Phys. Rev. **80**, 108 (1950).

U3. Coincidence Studies of the B^{10} Gamma-Rays.* S. M. SHAFROTH AND S. S. HANNA, *Johns Hopkins University.*—The gamma-rays produced in the $Be^9(d, n)B^{10*}(\gamma, \gamma)B^{10}$ reaction[1] have been studied with two sodium iodide scintillation counters operated in coincidence. Both thin and thick targets of beryllium were bombarded with deuterons at various energies below 1 Mev. In single channel spectra, structure was observed corresponding to the 0.41, 0.72, 1.02, and 1.43-Mev gamma-rays.[1] At higher energies the interpretation of the spectra is difficult because of the complex response of the crystal. The 2.87-Mev gamma-ray can be identified and with less certainty, the 2.15-Mev gamma. In addition, the 3.37-Mev radiation from Be^{10} was observed. With the counters operated in coincidence the 1.02, 1.43, and 2.87-Mev gammas were found to be in coincidence the 1.02, 1.43, and 2.87-Mev gammas were found to be in coincidence with the strong 0.72-Mev radiation. Preliminary angular correlation measurements have been carried out on the 2.87−0.72 and the 1.02−0.72 cascades. To within about 10 percent the coincidence yields are isotropic. In the latter correlation there is an indication of a 10 percent effect of the form $1-0.1\cos^2\theta$. Work is in progress to determine the extent and the effect on these measurements of background correlations arising from the imperfect discrimination of the sodium iodide counters.

* Aided by a contract with the Atomic Energy Commission.
[1] Rasmussen, Hornyak, Lauritsen, and Lauritsen, Phys. Rev. **77**, 617 (1950).

U4. β-spectrum of C^{14}.* C. S. WU AND A. SCHWARZSCHILD, *Columbia University.*—Recent determinations of the parity of C^{14} and N^{14} showed that both of these nuclides have even parity; therefore, C^{14} is expected to undergo an allowed β-transition according to G-T selection rules ($\Delta I=1$, no). The extremely long half-life (log ft ~9) of C^{14} still remains to be explained. Whatever explanation is proposed for the decay of C^{14}, it is important to make certain of the shape of its β-spectrum, particularly the reported deviations from the allowed shape. To avoid the distortion of the β-spectrum resulting from the nonuniformity of the source, a vacuum evaporated succinic acid ($HOOCC^{14}H_2CH_2COOH$) source synthesized with active C^{14} was prepared. The average thickness of the source is less than 50 μg/cm², and the backing consists of a Formvar film of 10 μg/cm². The detector in the solenoid spectrometer is a G-M counter provided with a thin Formvar film of ~25 μg/cm². The spectrum is straight all the way down to 25 kev. Any deviations from linearity can be excluded. Comparisons of the β-spectrum obtained with chemically deposited sources will be discussed.

* Supported by the Atomic Energy Commission.

U5. Branching Ratio and Gamma-Ray Order in the Decay of Sc^{46}.* F. H. SCHMIDT AND G. L. KEISTER, *University of Washington.*—The β-decay of 84-day Sc^{46} occurs to two excited states in Ti^{46}. A 0.36-Mev group accounts for most of the transitions; a weak high energy group decays to the intermediate level. High specific activity Sc^{46} was obtained from Oak Ridge and examined in a ring focus solenoidal spectrometer. Corrections were made for the Compton electron contamination of the high energy β-branch. This was accomplished by assuming that the number of electrons observed is given by $N+ax^2$, where N is the number of beta-electrons, ax^2 is the number of Compton electrons, and x is the average source thickness. By comparing two sources of known strength, N can be determined in terms of the counting rates, and the ratio of source thicknesses. The branching ratio of the high energy component was found to be 0.22 percent ±0.05 percent. In agreement with Porter and Cook,[1] the upper energy limit obtained is 1.25±0.03 Mev, and a Kurie plot of the corrected spectrum is convex toward the energy axis. Internal conversion data are in agreement with Moon *et al.*

* Partially supported by the U. S. Atomic Energy Commission.
[1] F. T. Porter and C. S. Cook, Phys. Rev. **81**, 640 (1951).

U6. Degradation of Co^{60} Gamma-Rays in an Infinite Water Medium.* M. M. WEISS AND W. BERNSTEIN, *Brookhaven National Laboratory.*—The attenuation and change in shape of the Co^{60} gamma-ray spectrum has been investigated as a function of distance from the source in an "infinite" water medium using a scintillation spectrometer. It was found convenient to divide the spectrum into three energy ranges, 0–0.150 Mev, 0.150–1 Mev, and above 1 Mev, and each was investigated independently. The shape of the low energy region does not change with distance between 100–200 cm

and shows a pronounced peak at 55 kev. The attenuation is slower than that calculated for the primary, using the narrow beam absorption coefficients and the inverse square law. Because of small angle scattering the primary spectrum shows a gradual loss in resolution, and the two lines are indistinguishable at 200 cm. The attenuation of the intermediate energy region follows that of the low energy region, and the change in shape shows a gradual buildup of lower energy components. The experimental results are in good agreement with the theoretical calculations of Spencer and Fano,[1] and comparison of the theory and the experimental data will be given.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] L. V. Spencer and U. Fano, J. Research Natl. Bur. Standards **46**, 446 (1951).

U7. Measurement of the Directional Correlation of the Ni^{60} Gamma-Gamma-Cascade. J. S. LAWSON, JR., H. FRAUENFELDER, AND W. K. JENTSCHKE, *University of Illinois.*—Recently reported values[1] of the anisotropy of the Ni^{60} gamma-gamma-cascade have been in disagreement with the theoretical prediction. For the remeasurement of this anisotropy a conventional coincidence set-up was used, employing NaI(Tl) scintillation counters as detectors. A pile irradiated, metallic cobalt source was used. Scattered quanta were discriminated against in two different ways, first by using absorbers in front of the counters and low discriminator levels, secondly, by using high discriminator levels and no absorbers. The measured values of the anisotropy were found to be different in the two arrangements. However, an experimental determination of the effective solid angle of the counters in the two set-ups showed that they were also different. When this was taken into account, the two methods agreed, giving an average value of the anisotropy of 0.165 ± 0.003, in good agreement with theory. The reason for the disagreement of the earlier measurements cannot, however, be decided upon as yet.

[1] Aeppli, Frauenfelder, Heer, and Ruetschi, Phys. Rev. **87**, 379 (1952).

U8. Metastable States of Ge^{73}.* JOAN P. WELKER, A. W. SCHARDT, J. J. HOWLAND, JR., AND G. FRIEDLANDER, *Brookhaven National Laboratory.*—The decay scheme of As^{73} has been studied. The two transitions of 54 and 13.5 kev found by Johansson[1] to follow the electron-capture decay were confirmed by scintillation counter pulse-height analysis. The 13.5-kev transition is so highly converted that it could be observed only with a NaI crystal grown with As^{73} incorporated in it. The 13.5-kev transition was shown to follow the 54-kev transition, and to have a half-life of 4.6 microseconds. This was established by triggering an oscilloscope sweep with the 54-kev pulses and photographing the time distribution of 13.5-kev pulses on the oscilloscope screen. By similar experiments in which the germanium x-rays accompanying electron capture in As^{73} were used to trigger the sweep and the 54-kev pulses displayed on the screen, the half-life of the 54-kev transition was shown to be greater than 900 microseconds. An upper limit of 10 seconds has been placed on this half-life by rapid chemical separations of germanium from As^{73}.

* Research carried out under contract with the U. S. Atomic Energy Commission.
[1] S. Johansson, Arkiv Fysik **4**, 273 (1952).

U9. Angular Correlation of the Gamma-Rays of Sr^{88}.* J. VARMA, B. L. SARAF, AND W. B. TODD, JR. (introduced by W. F. G. Swann), *Bartol Research Foundation of the Franklin Institute.*—Recent measurements of conversion coefficients[1] prompted us to reinvestigate the angular correlation of the Sr^{88} gamma-rays. The gamma-rays were detected with NaI-scintillation counters. Only pulses corresponding to energies above 630 kev were accepted. Using the method of least square fit, our data, corrected for angular resolution, can best be represented by the correlation function $W(\theta)=1-0.107\cos^2\theta$; the statistical uncertainty of the coefficient is 1 percent. The only spin assignment compatible with the observed correlation and the conversion information as well as the cross-over intensity is 3–2–0. The largest admixture permitted by the observed coefficient is 0.001 percent of $M2$ in $E1$.

* Assisted by the joint program of the Office of Naval Research and the Atomic Energy Commission.
[1] F. R. Metzger and H. C. Amacher, Phys. Rev. **88**, 147 (1952).

U10. Radiations from Zr^{95}.* PHILLIP S. MITTELMAN,† *Rensselaer Polytechnic Institute.*—Studies have been made with a high resolution beta-ray spectrometer of the continuous beta-spectra and the conversion lines resulting from the decay of Zr^{95}. Using a mixed $Zr^{95}-Nb^{95}$ source three conversion lines were found in the vicinity of 750 kev. Studies with Nb^{95} rich sources and $K-L$ energy differences lead to an assignment of two of these lines to the Zr^{95} decay and one to the Nb^{95} decay. The energies of the Zr^{95} gamma-rays are 722.0 kev and 754.4 kev. The Nb^{95} gamma-ray has an energy of 764.0 kev. The energy measurements were made using a mixed $Cs^{137}-Zr^{95}-Nb^{95}$ source. A third conversion line resulting from the decay of Zr^{95} was found corresponding to a gamma-ray with an energy of 235 kev. Two allowed Zr^{95} beta-spectra with end points at 364 kev and 396 kev were resolved. The ratio of the total number of electrons in the 364-kev branch to that in the 396-kev branch is 1.4. Conversion coefficients and level assignments will be presented. Beta-gamma angular correlation measurements made on Zr^{95}, accepting both beta-gamma cascades noted above, yielded a value of 0.00 ± 0.03.

* This work was supported by the United States Atomic Energy Commission.
† Now at Nuclear Development Associates, Inc., White Plains, New York.

U11. Internal Conversion Coefficients of Niobium-95 and Zinc-65 (actually Mo-95 and Cu-65). E. F. STURCKEN AND A. H. WEBER, *Saint Louis University.*—The "thick" converter method recently developed by Thomas and Lauritsen[1] has been employed to determine N_γ in the conversion coefficient ratio N_e/N_γ. The internal conversion and Compton electron spectra were analyzed with a thin lens magnetic spectrometer. Geometry was identical in all experiments. The internal conversion coefficient of niobium-95 was also determined by comparison with its beta-spectrum. The results were α (thick converter method—N_γ determined from a high energy segment of the Compton electron spectrum), Nb-95, $\alpha=1.4\times10^{-3}$; Zn-65, $\alpha=2.5\times10^{-4}$; α (N_γ determined from beta-spectrum), Nb-95, $\alpha=1.76\times10^{-3}$; γ(Nb-95), 771 Mev, $E_{max}=0.171$ Mev; γ(Zn-65), 1.10 Mev. From Rose's Table[2] the experimental conversion coefficients are consistent with electric quadrupole radiation for Nb-95 and Zn-65. In the latter case there is a possibility of a slight admixture of magnetic dipole.

[1] R. G. Thomas and T. Lauritsen, Phys. Rev. **88**, 969 (1952).
[2] M. E. Rose *et al.*, U. S. Atomic Energy Commission, ORNL-1023 (1951).

U12. Conversion Coefficients and Spectrum Shapes from Sb^{124}.* E. P. TOMLINSON, *Bryn Mawr College*, S. L. RIDGWAY AND K. GOPALAKRISHNAN, *Princeton University.*—The electrons emitted in the decay of Sb^{124} have been measured with a high resolution magnetic spectrometer of the Siegbahn type. Conversion electrons have been observed corresponding to the known γ-rays of energies 604, 648, 725, and 1697 kev. The ratios of number of electrons in these conversion lines to the number in the 603 K line are as follows: 603 L, 0.13; 603 M (not resolved but estimated from line shape), 0.03; 648 K, 0.054; 725 K, 0.078; 1697 K, 0.034. The number of 603 K conversions identifies the transition here involved almost certainly as electric quardupole. Interpretation of the numbers for the other three transitions depends on knowledge of either the relative γ-ray intensities or the decay scheme of Sb^{124}, including the relative intensities of the β-components and the

branching ratios in the cases of various possible cross-over transitions. In pursuit of the latter knowledge the continuous β-spectrum has been measured with some care, and various possible correction factors have been tried for the several components of this complex spectrum. At present, it can be said that our data confirm the need for a correction factor on the high energy component and add the information that the next to highest energy component differs from the allowed shape.

* This work was supported by the Atomic Energy Commission and the Higgins Scientific Trust Fund.

U13. The Disintegration of Sb^{124}.* R. J. D. MOFFAT, N. LAZAR, AND L. M. LANGER, *Indiana University.*—The disintegration of Sb^{124} has been reinvestigated with magnetic spectrometer, scintillation pulse height, and coincidence techniques, and the data have been reanalyzed in an attempt to resolve the apparent inconsistencies among the observed beta-spectrum shape, the β-γ angular correlation, and the predictions of the shell model. Whereas the earlier analysis,[1] based upon fitting a "unique" once forbidden shape to the highest energy beta-group, led to inner groups which were not quite in agreement with the gamma-rays, a new analysis compatible with a mixed beta-interaction[2] for a $\Delta I = 1$, *yes* transition does lead to a consistent energy level scheme. The resulting maximum energies and intensities of the beta-groups are; 2.319 Mev, 20.6 percent; 1.602, 7.3 percent; 0.966, 9.0 percent; 0.61, 49 percent; 0.24, 14 percent. The gamma-ray energies are 0.603, 0.716, 0.641, 1.68, and 2.09 Mev. The internal conversion coefficient (3.4×10^{-3}) and $K/L+M$ ratio (7.9) of the 0.603-Mev transition agree with the values expected for $E2$. The 2.317-Mev beta-transition is to the 0.603-Mev state, and all the gamma-rays feed through this level.

* This work was assisted by a grant from the Frederick Gardner Cottrell Fund of the Research Corporation and by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] Langer, Moffat, and Price, Phys. Rev. **79**, 808 (1950).
[2] H. M. Mahmoud and E. J. Konopinski, Phys. Rev. **88**, 1266 (1952).

SATURDAY MORNING AT 9:30

Shoreham, West Ballroom

(W. A. FOWLER presiding)

Reactions of Transmutation and Inelastic Scattering III,

UA1. (d, p) Reactions with Separated Krypton Isotopes.* G. W. WHEELER, R. B. SCHWARTZ, AND W. W. WATSON, *Yale University.*—Samples of krypton gas with marked changes in the relative abundances of the six isotopes have been produced by the thermal diffusion method. We have used two 3.5-meter glass hot-wire columns convectively coupled and with 250-cc reservoirs at each end. The gap space was 4.5 mm and the power input 200 watts per meter. The pressure *vs* separation factor curve has a broad maximum at about 50 cm of Hg. At $p = 45$ cm of Hg, the equilibrium (7 days) fractional changes in concentration (percent of isotope in sample/percent of isotope in normal Kr) were:

Mass Number:	78	80	82	83	84	86
"Heavy" end:	0.006	0.045	0.24	0.55	0.96	2.1
Middle of column:	0.01	0.33	0.83	1.05	1.10	0.76
"Light" end:	380.	3.4	2.2	1.4	0.82	0.17

Krypton gas samples similar to these are being used as targets for (d, p) reaction studies with 3.9-Mev deuterons. The Q value of the longest range proton group so far observed is 3.7 ± 0.3 Mev. Further data on the proton groups will be presented.

* This work was supported by the U. S. Atomic Energy Commission.

UA2. The $Bi^{209}(d, p)B^{210}$ Q Value.* NATHAN SANDERS WALL, *Massachusetts Institute of Technology.*—The Q value for the reaction $Bi^{209}(d, p)Bi^{210}$ has been found to be 1.94 ± 0.05 Mev in agreement with Harvey.[1] The 15-Mev deuterons of the Massachusetts Institute of Technology cyclotron were used to bombard a bismuth metal foil, and the scattered particles were examined with a NaI(Tl) spectrometer. By analyzing the proton groups from two reactions of known Q value and the proton group being studied, the deuteron beam energy, the calibration of the spectrometer, the energy of the unknown proton group, and consequently its Q value can be determined. It was also found that no higher energy proton group of intensity greater than 1/30 that of the 1.94-Mev state, at 45° to the beam, was present. Considering an extreme single-particle model[2] and deuteron stripping theory,[3] it is possible for a proton group of about 400-kev more energy with an intensity of 1/200 the 1.94-Mev state to exist. This would not be detected in the present experiment but if present would complete the closed cycle involving the lead isotopes mentioned by Kinsey *et al.*,[4] as Pryce[2] has pointed out.

* Supported in part by a joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.

[1] J. A. Harvey, Phys. Rev. **81**, 353 (1951).
[2] M. H. L. Pryce, Proc. Phys. Soc. (London) **A55**, 773 (1952).
[3] W. Tobocman and F. Friedman, Phys. Rev. **87**, 203 (1952).
[4] Kinsey, Bartholomew, and Walker, Phys. Rev. **82**, 380 (1951).

UA3. Secondary Particles Resulting from High Energy Bombardment. R. W. DEUTSCH, *University of California, Berkeley.*—Continuing a program which has been previously described,[1,2] thin targets of Be, Al, Ni, Ag, Au, and U have been bombarded by 332-Mev protons and 187-Mev deuterons. The yields of secondary particles, primarily hydrogen and helium isotopes, are compared with those from 375-Mev alpha-bombardments.[2] An attempt is made to explain the results by the evaporation theory as formulated by LeCouteur.[3] An angular distribution of secondary particles for the same targets bombarded by 240-Mev alphas has also been determined. In this experiment, secondary particles emitted at 0°, 45°, and 135° to the incident beam direction are observed using nuclear track plates as detectors.

[1] W. H. Barkas and H. Tyren, Phys. Rev. **89**, 1 (1953).
[2] R. W. Deutsch and W. H. Barkas, Bull. Am. Phys. Soc. **27**, 17 (1952).
[3] K. J. LeCouteur, Proc. Phys. Soc. (London) **A63**, 259 (1950).

UA4. Nuclear Reactions Produced in the Brookhaven Cosmotron.* J. M. MILLER AND G. FRIEDLANDER, *Brookhaven National Laboratory.*—Preliminary radiochemical studies have been made on lead and copper targets irradiated with the 2-Bev proton beam of the cosmotron. With average beam intensities of 10^8 to 10^9 protons per second, some products are found to have saturation activities of the order of 10^6 to 10^7 dpm per gram of target. The observed relative yields of certain products show marked deviations from those found with 300- to 400-Mev protons. For example, in cosmotron-irradiated led, activities in the rare earth region (almost entirely neutron deficient nuclides) have very large yields

while, at lower bombarding energies, this region constitutes the trough in the yield curve between "spallation" and "fission" products, as verified by a lead bombardment with 370-Mev protons at the Nevis cyclotron. In a copper target the yields of Ni^{57}, Co^{55}, Fe^{59}, K^{42}, Na^{24}, and Na^{22} were all found to be comparable while at 300–400-Mev bombarding energy the yields of the last three are lower by about a factor of 50 than the others.[1]

* Research carried out under the auspices of the U. S. Atomic Energy Commission.
[1] Batzel, Miller and Seaborg, Phys. Rev. **84**, 671 (1951). D. H. Greenberg and J. M. Miller, Phys. Rev. **84**, 845 (1951).

UA5. (p, pn) and $(p, \alpha n)$ Excitation Functions. E. NEWMAN, B. L. COHEN, AND T. H. HANDLEY, *Oak Ridge National Laboratory.*—Excitation functions for (p, pn) and $(p, \alpha n)$ reactions in several elements have been measured using the internal 24-Mev proton beam of the ORNL 86-inch cyclotron. Effectively monoenergetic protons are obtained by cutting off the high energy "tail" of the incident proton energy spectrum with a probe inserted 180° from the target. The low energy "tail" causes no difficulty since these excitation functions increase sharply with energy. The measurements are carried out by standard stacked foil techniques; the current is determined from the published $Cu(p, n)$ cross section. An analysis of the data yields approximate energy spectra of the emitted alphas and protons. It is readily apparent that the Coulomb barriers encountered by emitted charged particles are identical with those experienced in their capture. Just as in the neutron case, the observed yields of charged particles from heavy elements are much larger than predicted by statistical theory. In addition, the observed cross sections continue to rise steeply after the theoretical ones level out which indicates that an excessive number of high energy particles are emitted. Measurements of deuteron yields using activation detection techniques* are in progress to determine how much (p, d) reactions contribute to the activities produced by (p, pn) reactions.

* Abstract on UA6, this meeting.

UA6. Measurement of Angular Distributions of Nuclear Reaction Products with an Internal Cyclotron Beam. B. L. COHEN, R. V. NEIDIGH, AND E. NEWMAN, *Oak Ridge National Laboratory.*—Angular distributions of elastically scattered protons and of deuterons, tritons, and alphas from (p, d), (p, t), and (p, α) reactions are being measured with the internal 22-Mev proton beam of the ORNL 86-inch cyclotron. The particles are detected by observing the activities induced by them—$Cu(p, n) \rightarrow 38$ min for protons, $Pd(d, p) \rightarrow 3.3$ hr and $Na(d, p) \rightarrow 15$ hr for deuterons, $Co(t, p) \rightarrow 1.6$ hr for tritons, and $Cu(\alpha, n) \rightarrow 9.4$ hr for alphas. Energy discrimination is obtained by absorbers. The energy and energy distribution of the incident beam are found by measuring the excitation function for $Cu(p, n)$ and comparing with published data. The angles are determined (within $\frac{1}{4}°$) by beam locating experiments and checked by the Rutherford law for elastic scattering from heavy elements at small angles. The current is monitored by neutron counters and measured by counting the activity in the target after bombardment. This is calibrated in a separate run against the published $Cu(p, n)$ cross section. The target is cooled by radiation only. The background is reduced (to <5 percent at most angles) by various types of carbon shielding. The solutions of other difficulties will be described, sample results will be shown, and extension to detection of other particles will be discussed.

UA7. Inelastic Scattering of 18.3-Mev Protons.* P. C. GUGELOT AND H. A. LAUTER, *Princeton University.*—Spectra of protons inelastically scattered from 0.0001-inch foils of Al, Fe, Ni, Cu, Ag, Sn, and Pt have been measured with a NaI(Tl) scintillation counter. The pulses were displayed on a Tectronix oscillograph and photographed on a moving film. Measurements were carried out at 60° and 150° to the incident beam. In the lower energy range of the spectra the intensity of the scattered protons is the same for 60° and 150°. In the high energy range the scattered intensity is larger in the forward direction. Relative values for the level densities of the residual nuclei may be obtained from these measurements. It appears that the level density cannot be represented by $\omega = \exp(aE)^{\frac{1}{2}}$. At low excitation energy E of the residual nucleus the level density changes slowly with E. At large excitation energy ω increases rapidly with E. For example, the relative level density of Ag may be represented by $\omega = 7.6\ 10^{-6}\ \exp E/0.72 + \exp E/4.9$.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

UA8. Energy Distributions of Fission Fragments.* JOHN S. WAHL, *Los Alamos Scientific Laboratory.*—The energies of fragments from fission of U^{235}, U^{238}, and Pu^{239} by 14-Mev neutrons, from fission of U^{238} by 2.5-Mev neutrons, and from fission of U^{235} and Pu^{239} by thermal neutrons have been measured in a single Frisch grid ionization chamber. The energy distributions for fast neutrons are similar to those previously obtained for fission by thermal neutrons. The most probable energies of the light and heavy fragments for fission by 14-Mev neutrons change only by ~1 Mev from their values for slow neutron induced fission. A rise in the height of the valley between the peaks for fission induced by 14-Mev neutrons may correspond to an increase in the probability for symmetrical fission. A double Frisch grid chamber has been used to measure simultaneously the energies of both fragments from fission of U^{235} by 14-Mev neutrons. The main change in the distribution of fission modes from that for thermal neutron induced fission is the increased probability by a factor of 100 for symmetrical fission.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

UA9. Yield Distribution in Proton Fission of Uranium. W. H. JONES,* J. H. PAEHLER, T. H. HANDLEY, and A. TIMNICK,† *Oak Ridge National Laboratory.*—A target consisting of stacked foils of normal uranium interleaved with aluminum absorbers was bombarded at a fixed radius in the 86-inch fixed-frequency proton cyclotron. The beam energy was determined from the proton range in copper and the known p, n and $p, 2n$ excitation curves of Cu^{63}. The uranium foils were dissolved in acid and standard radiochemical procedures used to separate As, Y, Mo, Ru, Ag, Cd, Sn, Ba, Nd, and Sm. These ten were chosen for suitable mass intervals, reasonable half-life, and proven chemistry. Relative yields were determined in terms of known yields by comparing the activities obtained with those resulting from identical chemistry on comparable samples after thermal neutron fission. Data taken show the expected shift[1] toward symmetric fission with increasing bombardment energy. For example, the yield ratio for Ag^{111}/Mo^{99} (taken as 0.0029 for thermal neutron fission) is 0.21 at 11.9-Mev proton energy, 0.28 at 15.0 Mev, and 0.36 at 18.4 Mev.

* Research Participant from Emory University.
† Research Participant from Michigan State College.
[1] Fowler, Jones, and Paehler, Phys. Rev. **88**, 71 (1952).

UA10. Short Resolution Time and Short "Dead" Time Coincidence Counting Equipment. RICHARD MADEY, *University of California, Berkeley.*—The combination of a scintillation counter pulse shaping circuit and a crystal diode coincidence circuit has a resolution time and a "dead" time of about three millimicroseconds. The short "dead" time is

achieved by delay line clipping of the scintillation counter pulses at the output of the photomultiplier tube. If shaped coincident pulses from two photomultipliers are applied to the input grids of a double triode, the resultant pulse at the common plate connection is not lengthened. If the two photomultipliers view a common scintillator, then this "adder" circuit improves the detection efficiency over a larger scintillator area. The coincidence circuit operates on slightly lower level input pulses if crystal diodes are used instead of vacuum tubes for mixing the input pulses. The circuit also uses the diode clamp that was first described by Garwin.[1] Another diode clamp, biased in the reverse direction, was introduced to improve the discrimination ratio. The equipment has been tested with cosmic rays, radioactive beta-sources (Ce^{144} and Sr^{90}), and pulsed radiofrequency beams of photons,[2,3] protons,[3] and deuterons.[3]

[1] R. L. Garwin. Rev. Sci. Instr. 21, 569 (1950).
[2] Madey, Bandtel, and Frank, Bull. Am. Phys. Soc. 27, 15 (1952) and a forthcoming article.
[3] See abstracts UA11, UA12, and UA13, this bulletin.

UA11. The Photoproduction of Negative Pions from Deuterium. KENNETH C. BANDTEL, WILSON J. FRANK, AND RICHARD MADEY, *University of California, Berkeley.*—The spectrum of negative pions produced by monoenergetic photons on deuterium was calculated by LeLevier[1] for pions at 120° and one of the protons at 20°. These recoil angles result when a pion is photoproduced from a free nucleon; further, the correlated angles remain very nearly the same for photon energies from 240 Mev to 340 Mev. The main part of the spectrum is peaked at the free production energy. Kinematics allow the two protons to have small relative energy even though their absolute energy is comparatively large. If the final protons are in a ^1S state, the ^1S proton-proton interaction and the phase space factor cause a sharp rise in the cross section at the high energy end of the pion spectrum. A comparison is made of the calculated with the measured ratio of the cross section integrated over the bremsstrahlung spectrum at high pion energies to that at lower pion energies. The combination of pion range and proton time-of-flight separates the condition of small relative energy from the other dynamical configurations of the two final nucleons. Three millimicrosecond resolution time and dead time counting equipment,[2] together with the pulsed character of the photon beam,[3] was used to discriminate against electron background from the CD_2 and C targets.

[1] R. LeLevier. Phys. Rev. 85, 771 (1952).
[2] See abstract UA10, this bulletin.
[3] Madey, Bandtel, and Frank. Bull. Am. Phys. Soc. 27, 15 (1952) and a forthcoming article.

UA12. Production of Tritons in Deuteron-Deuteron Collisions. CHARLES GODFREY, KENNETH C. BANDTEL, WILSON J. FRANK, AND RICHARD MADEY, *University of California, Berkeley.*—The reaction $d+d \rightarrow t+p$ was studied using an external beam of 190-Mev deuterons from the Berkeley 184-inch synchrocyclotron. Fast pulses from stilbene scintillation counter telescopes were employed to get coincidence counts between the triton and its correlated proton. The electronics used are described in an accompanying abstract by Richard Madey. Range and time-of-flight methods were used to reduce the effective background. Net counting rates were measured by taking a CD_2-C difference. The process was first identified by (1) moving the triton telescope in azimuth and elevation, (2) inserting a delay of 5×10^{-9} sec in the proton coincidence input, and (3) inserting enough absorber to just stop the postulated particle. In all cases the net counting rate disappeared. Values of the differential cross section were obtained at 30°, 45°, 60°, and 90° in the center of momentum system. The cross section rises from several microbarns at 90° to several hundred at 30°. The behavior is suggestive of a pick-up process.

UA13. Angular Distribution of the Process $p+d \rightarrow t+\pi^+$. WILSON J. FRANK, KENNETH C. BANDTEL, RICHARD MADEY, AND BURTON J. MOYER, *University of California, Berkeley.*—The bombarding particles are 341-Mev protons; the target deuterons are obtained by taking a CD_2-C difference. The kinematics allows the triton counters to be ten to eleven times further from the target than the pion counters without loss of solid angle. This geometry, together with three milli-microsecond resolution time and dead time coincidence counting equipment, aids in the identification of the process as well as in the suppression of accidental coincidences.[1] Relative cross sections were obtained for center-of-mass pion angles of 30°, 50°, 70°, 90°, 130°, and 150°. The main features of the angular distribution are a constant cross section from 180° to 90° and a rising cross section from 90° to 0°. The ratio of $(d\sigma/d\Omega_0)(0°)/(d\sigma/d\Omega_0)(90°)$ is between five and ten. The estimated total cross section is around five microbarns. This angular distribution is consistent with a repulsive core model for the nucleon.[2]

[1] For further details of the experimental method, see Frank, Bandtel, Madey, and Moyer. Phys. Rev. 87, 204 (1952); Bull. Am. Phys. Soc. 27, 15 (1952); and a forthcoming article. The electronics is discussed further by R. Madey in abstract UA10, this bulletin.
[2] See UA14, this bulletin.

UA14. Hard Core Interpretation of the Reaction $p+d \rightarrow \pi^++t$. SIDNEY BLUDMAN, *University of California, Berkeley.*—Employing the impulse approximation and neglecting the the production of pions in p-n collisions, Ruderman[1] has estimated the cross section for this reaction in terms of the cross section for the free particle process $p+p \rightarrow \pi^++d$. Since the measured[2] angular distribution disagrees with his result and is sensitive to the deuteron and triton wave functions at distances of the order $\frac{1}{2}\hbar/\mu c$, it has seemed worth while to consider the effect of a hard core in suppressing the deuteron wave function in the internal region. Hulthén deuteron wave functions with and without a hard core at $0.38\hbar/\mu c$ and an improved estimate for the triton wave function when the proton and a neutron are close together in a triplet state were employed in the calculation. The suppression of high momenta in the presence of a core reduces the total cross section and flattens the angular distribution in the back direction, in agreement with experiment. If the free-particle excitation function is extrapolated to be 3.1×10^{-28} cm^2/steradian for mesons of 78 Mev in the center of mass, the total cross section for 341-Mev protons is 9.1×10^{-30} cm^2 without the core, 5.2×10^{-30} cm^2 with the core.

[1] M. Ruderman, Phys. Rev. 87, 383 (1952).
[2] See abstract UA13, this bulletin.

SATURDAY MORNING AT 9:30

NBS, East Building

(H. L. DRYDEN presiding)

Division of Fluid Dynamics

Joint Session with the American Meteorological Society

Invited Papers

V1. Thermal Instability in Hydrodynamics and Hydromagnetics. S. CHANDRASEKHAR, *Yerkes Observatory.* (45 min.)

V2. Experiments in Fluid Mechanics for Meteorological Purposes. DAVE FULTZ, *University of Chicago.* (30 min.)

V3. The Use of High Speed Computing Machines in Meteorological Predictions. JULE CHARNEY, *Institute for Advanced Study.* (45 min.)

SATURDAY AFTERNOON AT 2:00

Shoreham, Main Ballroom

(M. L. POOL presiding)

Symposium on Hydrogen 3 and Helium 3 Reactions

VA1. Interactions of Tritium and Helium 3 with Light Nuclei Below 5 Mev. ARTHUR HEMMENDINGER, *Los Alamos Scientific Laboratory.* (25 min.)

VA2. Nuclear Reactions with Cyclotron-Accelerated Helium 3. J. H. FREMLIN, *University of Birmingham (England).* (25 min.)

VA3. Hydrogen 3 and Helium 3 Reactions with Medium-Heavy Nuclei. D. N. KUNDU, *Ohio State University.* (25 min.)

VA4. Thermo-Nuclear Reactions with Light Nuclei in the Stars. S. CHANDRASEKHAR, *Yerkes Observatory.* (25 min.)

VA5. Stripping and the Three-Body System. S. T. BUTLER, *Cornell University.* (25 min.)

SATURDAY AFTERNOON AT 2:00

Wardman Park, Burgundy Room

(J. R. PELLAM Presiding)

Cryogenics

W1. The Temperature Scale in the Liquid Helium Region. L. D. ROBERTS, *Oak Ridge National Laboratory,* AND R. A. ERICKSON, *University of Tennessee.*—Temperatures in the liquid helium region are usually obtained in terms of the equilibrium vapor pressures of a liquid helium bath. The liquid helium vapor pressure relationship in current use is that given by Keesom (1937) and Bleaney and Simon (1939). In 1946 Kistemaker proposed a slight modification to the above temperature scale deviating by 13 millidegrees at the lambda-point. By fitting a Curie-Weiss law to the measured magnetic susceptibility of $Mn(NH_4)_2(SO_4)_2 \cdot 6H_2O$ or $Fe\ NH_4(SO_4)_2 \cdot 12\ H_2O$ at 1.3°K, 4.2°K, and 77°K, we have compared the magnetic temperature so obtained with the accepted temperature scale. In the temperature region from 1.4° to 2.7° our results are in rather good agreement with those of Kistemaker. In addition we observe a small deviation in the same direction which rises to a maximum of 6 millidegrees at 3.5°K.

W2. Small-Angle Scattering of X-Rays from Helium I and Helium II. A. G. TWEET, *University of Wisconsin.*—CuK_α x-rays, isolated with Ross filters, and with Geiger counter detection, have been scattered at angles between 1.2 and 5.0 degrees from liquid helium at temperatures from 4.2° to 1.5°K. Collimating slits furnished an angular resolution of 0.35 degrees. The sample of liquid helium was contained in a thin-walled aluminum tube 2.39 cm in diameter enclosed in a metal cryostat. The temperature-dependence of the observed scattering was compared with the theoretical zero-angle liquid structure factor $L = NkTx_T/V$, where N/V is the number density of helium atoms, and x_T, the isothermal compressibility. $x_T = (c_P/c_V)x_S$, where x_S is the adiabatic compressibility. x_S was calculated from measurements of first sound velocity,[1] and (c_P/c_V) was calculated by the method of Groenewald.[2] The results are in good agreement between about 2.0°K and 3.5°K. There is no evidence for a maximum in the scattering *versus* temperature curve as suggested by Goldstein[3]

on the basis of the perfect Bose-Einstein gas, asymptotic model of liquid helium. The angular dependence of the scattering is small below 3.5°K. There is evidence for a greater angular dependence at 4.2°K.

[1] K. R. Atkins and C. E. Chase, Proc. Phys. Soc. (London) **A64**, 826 (1951).
[2] H. J. Groenewold, Nature **142**, 956 (1938).
[3] L. Goldstein, Phys. Rev. **83**, 289 (1951).

W3. Thermomechanical Effect in Liquid Helium II to 0.9°K.* D. H. ROGERS AND MELVIN A. HERLIN, *M.I.T.*—The thermomechanical pressure in liquid helium II has been measured as a function of temperature difference and ambient temperature to slightly below 0.9°K ambient. The full thermomechanical pressure as given by the London equation is observed. At the lower temperature limit the phonon contribution to the entropy is over half of the total entropy, indicating that the phonons contribute to the thermomechanical pressure reversibly as has been observed for the higher temperature excitations. A nonlinear dependence of thermomechanical pressure on temperature difference has been found to be completely explained by the change of entropy with temperature, substantiating the assumption of reversibility. It has been found possible to sustain a fairly large temperature difference across the filter element even at the low temperature end of the observed range without introducing irreversible effects.

* This work was supported in part by the Signal Corps, the Air Materiel Command, and the U. S. Office of Naval Research.

W4. Linear Velocity of the Helium II Film.* W. C. KNUDSEN AND J. R. DILLINGER, *University of Wisconsin*.—The velocity with which the He II film proceeds over initially dry spirals of copper wire and of stainless steel tubing filled with He II has been studied. He II is brought in contact with one and then the other of two points of the spiral 115 cm apart. The spiral is shaped so that each of these two points is just above one end, the lowest point, to which film proceeds and then forms drops. The linear velocity v is 115 divided by the difference in time to form the first drop over each of the two paths. Approximately 37 cm/sec was obtained for v for both types of spirals at 1.3°K. Volume flow rates were determined during the same experiment by measuring the rates at which the height of helium in a glass beaker under the spiral changed with and without helium coming over the spiral. Values of 19×10^{-6} cm³/sec cm and 31×10^{-6} cm³/sec cm were obtained at 1.3°K over copper and stainless steel, respectively. Assuming that transfer rates higher than those measured over glass surfaces are due to differences between the measured and microperimeter of the substrate,[1] a film thickness of 2.1×10^{-6} cm was obtained by dividing the volume flow rate, 7.8×10^{-6} cm³/sec cm, as measured over the glass beaker by v.

* This work was supported in part by the U. S. Atomic Energy Commission and in part by the Wisconsin Alumni Research Foundation.
[1] B. S. Chandrasekhar and K. Mendelssohn, Proc. Phys. Soc. (London) **65A**, 226 (1952).

W5. Helium Film Flow. JAMES B. BROWN, *Royal Military College of Canada*.—It is pointed out that the double beaker experiment of Daunt and Mendelssohn,[1] while setting an upper limit to the viscosity of the helium II film, does not necessarily have further implications as to the mechanism of film flow. In particular, it should be noted that the maintenance of a flow velocity of the order of 20 cm per second without a visible level difference does not by itself require a special explanation in terms of zero-point diffusion with no gravitational acceleration. In fact, flow relations essentially similar to that of the double beaker experiment can be maintained in a classical water syphon under suitable conditions. Because of this close connection between the helium film and an ordinary syphon, it was interesting to see whether the film would flow over heights appreciably greater than that of a liquid helium barometer at the vapor pressure of the experiment. Such flows have been observed and accounted for. The possibility of the double beaker experiment being complicated by thermomechanical effects has also been considered and experiments have been performed to exclude this possibility.

[1] Daunt and Mendelssohn, Nature **157**, 839 (1946).

W6. Heat of Mixing of He^3 in He^4. H. S. SOMMERS, JR., W. E. KELLER, AND J. G. DASH, *Los Alamos*.—Analysis of the vapor pressures of solutions of He^3 in He^4 has shown that there should be a large positive heat of mixing of the two liquids.[1] We have demonstrated its existence by mixing the liquids adiabatically at 1.1°K and observing a significant drop in temperature. A quantitative estimate of the mixing energy has been made at the same temperature by balancing the heat absorbed by mixing against the heat released by condensation of He^3 vapor. The value is in reasonable agreement with the predicted value of 3.2 cal/mole. The experiments will be described and certain implications drawn about the entropy of mixing.

[1] H. S. Sommers, Jr., Phys. Rev. **88**, 113 (1952).

W7. Lambda-Point Shift in He^3-He^4 Mixtures. J. C. KING AND HENRY A. FAIRBANK, *Yale University*.—Several different values of the rate of change of the lambda-temperature with respect to He^3 concentration for very low He^3 concentrations have been predicted by various authors.[1] Previous experimental data have been inadequate to distinguish between these possibilities. The velocity of second sound in liquid helium II has been measured close to the λ-point as a function of temperature and He^3 concentration. These measurements provide a rather precise method of determining the λ-point shift with He^3 concentration. For concentrations below 4 percent the λ-temperature decreases linearly with increasing concentration with a slope of -1.5 degree per mole fraction. Of the various proposed theories for the He^3-He^4 solutions[1] the predictions of de Boer and Gorter are in best agreement with this result provided a quadratic dependence of the Gibbs function G_4, for pure He^4, on the temperature is assumed. The fact that $(dT_\lambda/dX)_{X=0}$ is finite requires that there must be a discontinuity in the temperature derivatives of the vapor to liquid concentration ratio and the vapor pressure as suggested by de Boer.[2]

[1] J. G. Daunt, Phil. Mag. Supplement **1**, 209 (1952).
[2] de Boer and Gorter, Physica **18**, 565 (1952).

W8. Ultrasonic Measurements in Liquid Helium.*† C. E. CHASE,‡ *M.I.T.*—Measurements of the velocity and absorption of ordinary sound in liquid helium have been made in the temperature range from 0.85°K to the normal boiling point, using a pulsed ultrasonic technique at frequencies of 2, 6, and 12 Mc/sec. The velocity measurements indicate the absence of detectable dispersion over this frequency range and confirm the results of earlier measurements which indicated that the velocity becomes practically independent of temperature below 1.4°K and approaches the value 239 ± 2 m/sec at absolute zero. The attenuation measurements are in agreement with the results of Pellam and Squire over the temperature range covered by those authors and disclose a very rapid rise in the attenuation below 1.6°K. Above 1.2°K the quantity α/ω^2 is independent of frequency; a marked departure from this behavior at lower temperatures indicates the presence of relaxation effects. These results are in qualitative agreement with the theoretical predictions of Khalatnikov, whose calculations are based on the assumption of finite relaxation times for the processes leading to a change in the number of elementary excitations present in the liquid.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and the U. S. Office of Naval Research.
† Work done at the Royal Society Mond Laboratory, Cambridge, England.
‡ Introduced by Melvin A. Herlin.

W9. The Transmission of Slow Neutrons by Liquid Helium. L. GOLDSTEIN, H. S. SOMMERS, JR., AND J. G. DASH, *Los Alamos Scientific Laboratory.*—We have studied the total scattering cross section of liquid helium for slow neutrons, for He temperatures between 2 and 4°K and neutron energies from 3.5 to 100°K. For the slowest neutrons, the cross section per atom is smallest and independent of energy. As the neutron energy increases, the cross section rises rapidly and finally approaches asymptotically the free atom cross section. Lowering the liquid temperature lowers the value of the cross section at intermediate and small neutron energies. The present results at the higher energies are not compatible with the limiting model of liquid helium as an ideal symmetric fluid. The observations are not unlike what one could expect from a solid type of atomic ordering for such light atoms as He with a large zero-point and temperature motion. For even colder neutrons than those yet used, the cross section is expected to rise again because of the increasingly important relative motion effect of the neutrons and He atoms. Such an effect might yield information as to the velocity distribution of the He atoms.

W10. The Structure of Liquid Helium. JAMES REEKIE AND THOMAS S. HUTCHISON, *Royal Military College of Canada.*—The angular intensity distribution of x-radiation scattered by liquid helium has been measured at eight temperatures in the range from 4.2°K down to 1.27°K. Using a development of a method previously employed for this problem, typical "liquid-ring" diffraction pictures have been obtained above and below the λ-point, the microphotometer curves of which show a main maximum at a 2θ value of 28.5° and a secondary maximum at about 55°. After correcting for polarization and other geometrical factors, the intensity curves have been reduced to give the atomic distribution function. A method essentially similar to that described by Gingrich was used in the computations. The final results show that the configuration of the bulk liquid, both in the helium I and helium II regions, is best represented by a close-packed cubic arrangement with twelve atoms grouped at approximately 3.2A apart.

W11. Superconductivity of Titanium. M. C. STEELE AND R. A. HEIN, *Naval Research Laboratory.*—Critical magnetic fields for titanium have been measured from 0.23°K to 0.48°K, the zero-field transition temperature. The specimen was a crystal bar with a purity greater than 99.99 percent. The critical field curve for this specimen can not be represented by the usual parabolic relation. The slope dH_c/dT at $T=T_c$ was found to be 400 gauss/ degree. Previous workers[1,2] have found similar values, but recently reported data[3] is in disagreement with these results. The differences probably cannot be attributed to specimens since ours had a chemical purity and a measured hardness comparable to that reported recently.[3] Independent magnetic susceptibility measurements were made on the paramagnetic salt (chrome potassium alum) and the metal. A carbon-composition resistor was used to check the thermal contact between salt and metal. When thermal contact was poor the data were not reproducible and gave low values for T_c and dH_c/dT. The values reported above were found to be reproducible in three separate experiments.

[1] J. G. Daunt and C. V. Heer, Phys. Rev. **76**, 715 (1949).
[2] T. S. Smith and J. G. Daunt, Phys. Rev. **88**, 1172 (1952).
[3] Smith, Gager, and Daunt, Phys. Rev. **89**, 654 (1953).

W12. Electromagnetic Absorptivity of Metals at Low Temperatures. T. HOLSTEIN, *Westinghouse Research Laboratories.*—The effect of electron-electron interaction on the electromagnetic absorptivity of metals at low temperatures has been studied theoretically. The electron-electron interaction is treated phenomenologically in terms of a mean free path λ_e, defined as the mean distance a given electron travels before sharing its momentum with other electrons. Specific results have been obtained for the microwave region, where recent experiments of Chambers[1] appear to confirm the free-electron theory of Reuter and Sondheimer.[2] It is found that, in order to achieve an absorptivity, e.g., for Cu, comparable in magnitude with that of Reuter and Sondheimer, and hence with experiment, it is necessary to assume $\lambda_e \gtrsim 1600$A.

[1] R. G. Chambers, Proc. Roy. Soc. (London) **215**, 481 (1952).
[2] G. E. H. Reuter and E. H. Sondheimer, Proc. Roy. Soc. (London) **195**, 336 (1952).

W13. Adiabatic Magnetization of a Superconducting Sphere. R. L. DOLECEK, *Naval Research Laboratory.*—Temperature changes accompanying suppression of the superconductivity of a lead sphere by adiabatic magnetization have been investigated. From an initial temperature of 3.62 ±0.02°K, measurements were taken of the cooling produced by adiabatic magnetizations into the complete range of the intermediate state. The magnetic fields were applied as step functions of time and allowance was made for the resulting eddy current heating. The temperature changes observed on magnetization are in quantitative agreement with values predicted from calorimetric data and were found to be linearly dependent upon the magnitude of the field applied. Thus the measurements support the current interpretation of the entropy of a superconductor in the intermediate state and demonstrate the linear relation between the applied magnetic field and the fraction of normal metal produced in the intermediate state.

SATURDAY AFTERNOON AT 2:00

NBS, East Building

(CHARLES S. SMITH presiding)

Semiconductors

WA1. Recording of Temperature Dependent Electrical Properties of Semiconductors.[4] LUTHER DAVIS, JR., LAWRENCE RUBIN, AND W. D. STRAUB, *Raytheon Manufacturing Company.*—Utilization of the automatic features of a six-channel recorder scheduling external events has made possible rapid measurements of the temperature variation of resistivity and Hall constant of semiconductors. Samples with soldered end contacts and three gold alloy welded probes are mounted in a Dewar flask. This is then placed between the pole faces of a 60-cycle magnet, along with a stationary search coil. Scheduling of events is such that the following signals are sent to the recorder during a 24 second cycle: magnetic field strength, sample temperature, longitudinal electric field with magnetic field off and on, and two rectified 10-cycle Hall fields. The last two are generated at the difference frequency of a 70-cycle constant current and the 60-cycle magnetic field.[1] There is a 180° reversal of the magnetic field between the two Hall signals, which are averaged to minimize pickup effects.

A dc constant current generator is used when measuring longitudinal electric field. The maximum temperature change of about 6°C per minute introduces about 2°C error in measurements from 77°K to 370°K.

* Work supported in part by the U. S. Bureau of Ships, Signal Corps, and Air Corps.
[1] B. R. Russell and C. Wahlig, Rev. Sci. Instr. **21**, 1028 (1950).

WA2. Energy Band Structure of Diamond and Germanium Crystals. FRANK HERMAN, *R. C. A. Laboratories.*—A practical approach to the problem of determining the electronic structure of the diamond type of valence crystals is formulated. Using a judiciously chosen crystal potential, the required crystal eigensolutions are obtained by the method of orthogonalized plane waves first introduced by Herring. The main features of recently reported calculations of diamond[1] and germanium[2] are reviewed here in more detail. These solutions reveal certain features not brought out by earlier studies. For example, the essential difference in energy band structure in diamond and germanium arises as a consequence of the differing interactions between valence-conduction and core states, i.e., because the orthogonality requirements are not the same in the two cases. The present study demonstrates the effectiveness of the method of orthogonalized plane waves in handling valence crystals. Although crude approximations were introduced in setting up the crystal potentials and core eigenstates, most of the present results are believed to be more reliable than those previously published. The general plan of a more extended and more accurate calculation of germanium now in progress will also be discussed.

[1] F. Herman, Phys. Rev. **88**, 1210 (1952).
[2] F. Herman and J. Callaway, Phys. Rev. **89**, 518 (1953).

WA3. Piezoresistance Effect in Germanium. CHARLES S. SMITH AND J. R. HAYNES, *Bell Telephone Laboratories.*—The application of tensile stress has been found to produce a change in resistivity in germanium single crystals. The effect is anisotropic and is larger than that associated with the change of energy gap with volume dilation. If σ is the stress and $\delta\rho/\rho$ the corresponding fractional resistivity change, the quantity $(1/\sigma)(\delta\rho/\rho)$ in units of 10^{-12} cm^2 dyne^{-1} has been found to be -7 in the [100] direction and -91 in the [110] direction for 1.5 ohm-cm n-type material. The effect presumably has a small pressure coefficient since it has not been observed in previous hydrostatic pressure experiments. Assuming for the present the pressure coefficient to be zero and using the two observations quoted, the piezoresistance coefficients, defined by the tensor relation $\delta\rho/\rho=\pi\sigma$, turn out to be $\pi_{11}=-7$, $\pi_{12}=+3.5$, $\pi_{44}=-178$ in units of 10^{-12} cm^2 dyne^{-1}. Thus the effect is one of shear primarily. The shear coefficient for 0.6 ohm-cm p-type material is also large but is positive.

WA4. Nonlinear Semiconductor Resistors.* F. A. SCHWERTZ AND J. J. MAZENKO, *Mellon Institute.*—A phenomenological theory for the nonlinear voltage-current characteristic curve displayed by a granular aggregate of silicon carbide is presented. The theory, which should apply to granular semiconductors other than silicon carbide, is based on a very simple model of the aggregate and on the assumption that the essential resistance is located at the grain-grain contacts, the impedance of the bulk material being considered negligibly small. The current i is related to the voltage V by the equation

$$i=\frac{kAP^{n/m}d^{n-2}V^n}{t^n},$$

where A is the cross-sectional area of the aggregate, t the thickness, P the applied pressure, and d the average particle diameter. The constants k, n, and m are structure-sensitive, that is, they depend on the physical-chemical nature of the particles forming the aggregate. Factors influencing the values of these constants include impurity concentration in the semiconductor, elastic constants, and particle shape. The validity of this equation is supported by careful measurements made on granular aggregates of silicon carbide.

* Multiple Fellowship on Computer Components, sustained by the Electronics Directorate of the Air Force Cambridge Research Center, RDC.

WA5. Thermoelectric Power in Germanium Single Crystals.* H. P. R. FREDERIKSE, *Purdue University.*—The thermoelectric power Q in germanium crystals has been found to decrease with increasing concentration of carriers. As a function of temperature agreement with $Q=(k/e)$ (const$-\zeta/T$), was obtained above 200°K. Below this temperature Q rises sharply above the value given by the above formula, then reaches a maximum of several mv per degree near 15°K and approaches zero as $T\rightarrow 0$. The above formula is obtained on the assumption that the phonons of the lattice are in equilibrium. This, however, does not hold in insulators and semiconductors where most of the heat flow is carried by phonons. It can be shown that this leads to an extra term for Q proportional to the ratio l_L/l_e of phonon to electron mean free paths. The former can be estimated from the thermal conductivity where as the latter is known from electrical measurements. Using these values the sharp rise of Q below 200°K can be accounted for by the extra term.

* Supported by a U. S. Signal Corps contract.

WA6. Lifetime of Minority Carriers in Localized Crystal Regions. M. BECKER, M. CUTLER, T. FIRLE, R. SHULMAN, AND W. SPITZER, *Hughes Research and Development Laboratories.*—Recombination centers have been shown[1] to be a major factor in determining the lifetime of injected minority carriers in germanium crystals. Since the density of these centers may vary throughout a crystal, it has been considered desirable to minimize the region in which recombination is measured. The manner in which this minimum volume is determined by the geometry and the diffusion length will be discussed. Two independent methods have been devised to confine measurements to the minimum possible volume. One method is a variation of the Haynes and Shockley[2] sweeping technique, while the other utilizes conductivity modulation of the spreading resistance of a point contact. Experimental results will include lifetime variations along filaments and comparisons between the methods.

[1] R. N. Hall, Phys. Rev. **87**, 387 (1952).
[2] J. R. Haynes and W. Shockley, Phys. Rev. **81**, 835 (1951).

WA7. Carrier Traps in Germanium at Low Temperatures.* D. NAVON AND H. Y. FAN, *Purdue University.*—At low temperatures the decay of holes injected into n type germanium is not a simple exponential curve[1] but can be resolved into two or sometimes three exponential components. The time constants of the slow components (48 μsec and 280 μsec, respectively, for a 9 ohm-cm sample at 195°K) were independent of the surface treatment, etching or grinding, and remained unchanged as the sample thickness was reduced from 0.21 to 0.04 cm. With ground surfaces the time constant of the fast component decreased from 14 to 5 μsec as the thickness was reduced whereas with etched surfaces it remained approximately unchanged at 20 μsec. The slow components can be quenched by illuminating an etched (not ground or polished) surface of the sample with white light. The slow components are not affected by increasing the dc voltage applied across the sample, and the decay lasts much longer than the time required to sweep all mobile excess carriers out of the sample. These results indicate the existence of traps for the injected holes.[2]

* Work supported by a U. S. Signal Corps contract.
[1] Navon, Bray, and Fan, Proc. Inst. Radio. Engrs. **40**, 1342 (1952).
[2] Gebbie, Nisenoff, and Fan, Bull. Am. Phys. Soc. **28**, No. 2, 32 (1953).

WA8. Preparation of Junctions in Single Crystals by Surface Melting. K. LEHOVEC AND E. BELMONT, *Sprague Electric Company.*—Present methods of producing $p-n$ junctions in single crystals are based on the pulling of a single crystal from a melt. It is a drawback of these methods, as applied to the production of multiple junctions, that time enters as a parameter determining the width of the junction. In the following method the time is not a critical factor. The surface zone of a single crystal slice is melted by radiation while the bottom is cooled. The position of the interface between melted zone and solid zone is a function of (a) rate of heating from the surface, (b) rate of cooling from the bottom, and (c) geometry. The position of the interface can be shifted arbitrarily by changing (a) and/or (b). If the position of the interface is shifted slowly toward the top, the melt solidifies as a single crystal of same orientation as the bottom part. Impurities can be introduced at any given moment into the melted zone. In this manner $p-n$ junctions in germanium have been prepared with electric properties comparable to those in pulled crystals. $p-n$ junctions have been prepared also by melting a slice of p type crystal on a slice of n type crystal (or *vice versa*).

WA9. Some Electrical Properties of Elementary Boron.* L. W. FRIEDRICH AND V. P. JACOBSMEYER, *St. Louis University.*—Samples of pure elementary boron were prepared by pyrolysis of diborane at deposition temperatures ranging from 700°C to 1500°C. Those deposited at approximately 1000°C and at 1500°C showed best crystallinity. These also exhibited the most different values of resistivity; that of the 1500°C sample was about 10^6 ohm cm at room temperature, and that of the 1000°C sample was about 0.1 ohm cm. The activation energy of the 1500°C sample for apparently intrinsic conduction was 1.12 ev. Irradiation for 16 hours with Cu $K\alpha$ x-rays permanently increased the resistivity of the boron samples in a manner indicating that electrons, freed in the ionization by x-rays of donor type impurity centers, and combined with positive holes in the valence band of the boron to reduce the carrier concentration. The magnetoresistance of one sample was found to vary approximately as the fourth power of the magnetic field intensity.

* Research carried out under contract with U. S. Office of Ordnance Research.

WA10. Lattice Absorption in Diamond: A One-Dimensional Model. MELVIN LAX, *Syracuse University,* AND ELI BURSTEIN, *Naval Research Laboratory.*—The lattice absorption in diamond, silicon, or germanium can possibly be explained on the basis of a second order electric dipole moment, i.e., a moment quadratic in the displacements. To determine quickly the qualitative consequences of such an explanation, a calculation was performed on a one-dimensional lattice with some of the symmetry properties of diamond: two atoms per unit cell with a center of symmetry halfway between these atoms. Using these symmetry properties it was possible to reduce drastically the number of independent coefficients in the quadratic form. If interactions are neglected beyond second neighbors, only one coefficient remains, and the *form* of the absorption spectrum is determined. The vibrational transition involves two phonons, either of which may be created or destroyed. At temperatures well below the Debye temperature, only creation is possible. One of these phonons must be acoustical, and the other optical: speaking classically, an electric moment is produced only when an optical and acoustical vibration are simultaneously present. Furthermore, the momentum of the photon may be neglected, so that these phonons must have equal and opposite momentum. Finally, the short wavelength phonons are found to make the principal contribution. We expect that most of these qualitative conclusions will be borne out in a three-dimensional calculation.

SATURDAY AFTERNOON AT 2:00

NBS, Materials and Testing

(W. W. WATSON presiding)

General Physics; Biophysics

X1. Noise in Storage Tubes. STANLEY WINKLER AND SEYMOUR NOZICK, *U. S. Naval Material Laboratory.*—The performance of storage tubes is evaluated by their ability to accurately reproduce a given input signal, the maximum writing speed, the quantity of information which can be stored, the accessibility of stored data and factors related to efficiency of operation. All of these are affected by noise, and the importance of noise is accentuated by the low signal levels encountered at the output of storage tubes. Noise is defined as the undesired signal which constitutes the difference between the output of and the input to a storage tube. This noise is divided into random noise and transfer effect. Random noise is incoherent information and is similar to noise encountered in any electron tube device. The transfer effect is the regular functional distortion which is characteristic of individual storage tubes and is erroneous information coherent with the desired signal. A transfer function is defined as the operator which transforms the input signal into the output signal (excluding random noise). The sources of random noise and the transfer effect and their relative importance are discussed in detail. A definition of a noise figure for storage tubes is attempted. The results of preliminary measurements on experimental storage tubes are given.

X2. A High Accuracy, High Speed Shaft Position Digitalizer. DONALD H. JACOBS, MILTON E. PUGH, AND SEYMOUR SCHOLNICK, *The Jacobs Instrument Company.*—A previous paper[1] described a device for determining, in digital terms, the angular position of a shaft relative to a selected reference point. This digital value of shaft position could be recorded, or employed as the input to a digital computer. That digital converter could make readings to a high order of accuracy at low speed or to a lower order of accuracy at high speed. Recently a requirement for a device to give high accuracy at high speed has arisen, and the device described was conceived. This also uses a counting technique to determine the value of the unknown angle. However, instead of giving one determination of the angle for each rotation of the search probe, this device permits the measurement to be made during a very small angular motion of the search probe. Hence it is now possible to make a measurement of angle in less than 0.1 millisecond without the use of high speeds for the probe.

[1] D. H. Jacobs and S. Scholnick, Phys. Rev. **85**, 731 (1952).

X3. The Information Content of Living Systems. HAROLD J. MOROWITZ, *National Bureau of Standards.*—The living cell is an efficient unit for storing a large quantity of information

in a small volume. The ability of many cells to survive temperatures near absolute zero indicates that the information is stored exclusively in the molecular structure, the cells information storage being analogous to a punch card rather than electronic memory. Since many cells are able to survive almost complete drying it may be assumed that the cellular water is not a part of the information unit. The residual unit for bacterial cells has a mass of the order of 10^{-12} gram ($\sim 10^{10}$ atoms) and is composed largely of protein and nucleoprotein. From these data it is possible to make preliminary calculations of the information content of a bacterial cell.

X4. Improved Equilibrium Ultracentrifuge.* A. ROBESON,† N. SNIDOW, AND J. W. BEAMS, *University of Virginia.*—A 7.5-in. diameter ultracentrifuge rotor is magnetically suspended in a vacuum chamber (pressure 10^{-6} mm Hg) and driven to operating speed by an air turbine below the chamber. The turbine is connected to the rotor with a thin flexible shaft which passes through a vacuum tight gland and which is disengaged from the rotor at operating speed. The rotor coasts freely during the observations and loses less than 1 rps per day. The concentration across the ultracentrifuge cell is determined by the refractive index measured by an interferometer arrangement which employs both white light and monochromatic fringes. A shift of 0.05 fringe is measurable. When desired, the rotor speed may be held constant without observable heating by driving it in a manner similar to that of the rotor of a synchronous motor with piezoelectrically controlled circuits. The rotor speed may be measured to one part in 10^6 and the rotor temperature maintained constant to 0.01°C. The apparatus is especially adaptable to molecular weight determinations in the range from 300 to 10 000.

* Supported by Navy Bureau of Ordnance.
† U. S. Rubber Company, Fellow.

X5. A Series Method for the Comparison of Resistances. HAROLD J. HOGE, *Leeds and Northrup Company.*—A method of comparing resistances is described in which two sources of emf, each with an associated dropping resistor, are connected in series with two resistors to be compared in such a way that the latter are not adjacent. The circuit may then be adjusted so that the potentials at the two ends of one of these resistances are equal to the potentials at the corresponding ends of the other resistance, while both carry the same current. Convenient means of detecting and adjusting to this condition are described. The circuit may be used as an alternative to either the dc or the ac bridge. The method is suitable for work of either high or low accuracy. Its chief advantage over methods now in use is that it permits the continuous observation or recording of resistance without error due to uncontrolled changes in the resistances of the connecting leads. Readings are obtained directly, without the necessity of averaging or otherwise mathematically combining the results of more than one observation. If desired, more than two resistances to be compared may be included in the circuit, provided they are alternated with an equal number of emfs and associated dropping resistors.

X6. Very High Resistance Measurement. FRANK J. LYNCH AND CLARENCE L. WESENBERG, *Argonne National Laboratory.*—An instrument for the accurate measurement of resistance in the range of 10^9 to 10^{13} ohms is described. A constant current flows through the resistor under test, and the potential drop across it is measured with an electrometer. The constant current is the displacement current flowing into the plates of a standard condenser when the potential difference between the plates changes linearly with time. The potential drop across the resistor is measured by a recording dynamic condenser electrometer. The accuracy of the resistance measurement is dependent only upon the accuracy of wire-wound potential dividers and the dimensions of the standard condenser. The present accuracy is ± 0.25 percent, but better accuracy may be achieved. The time of measurement for this accuracy is about $6\,R \cdot 10^{-11}$ second.

X7. The Subject of Social Physics. JOHN Q. STEWART, *Princeton University.*—A minimum definition restricts social physics to consideration of the social role of such physical and measurable factors as time, distance, mass of material, availability of energy, and the numbers of people—analyses of data being conducted in ways that have succeeded in physics. Empirical regularities are stressed for which mathematical expressions exist. Many important results can be cited, but their significance is for sociology more than physics. However, it is proving advantageous to center maximum rather than minimum emphasis on physics—as the best universal model of advanced pure thought from which (in Leibnizian manner) conceptual patterns are deducible for subjects of widely different content. These isomorphisms stimulate in their turn reexamination of all the most general principles of physics itself. Such studies tend to re-establish physics as the "natural philosophy" which uniformitarian natural-law thinking represented it to be, before specialization enlarged the technological applicability of physics while deforming its cultural leadership. For example, Hegel's misnamed "thesis-antithesis-synthesis" pattern for describing progression seems allied to Henry's rule for electromagnetic induction; and the sharpened attention is so directed to the localization and progressive movement of energy finds that these characteristics have not yet been completely described in physics.

X8. The Inactivation of Desoxyribonucleic Acid by Bombardment with Deuterons and Electrons.* CYRIL L. SMITH, *Yale University.*—Commercially obtainable highly polymerized desoxyribonucleic acid (D.N.A.) was evaporated from solution on to glass cover slips and then bombarded with deuterons of maximum energy 3.7 Mev produced by the Yale cyclotron. The D.N.A. is assayed after placing the cover slips in a measured quantity of distilled water, by measuring the change in absorption of the solution at 2700A when it is depolymerized by means of desoxyribonuclease (D.N.A'ase). The activity-dose curve is logarithmic. Similar cover slips were also inactivated by electrons of 2 Mev energy produced by the Van de Graaff generator at the Brookhaven National Laboratory. The activity-dose curve is again logarithmic. From the slopes of these two curves a cross-sectional area and volume may, respectively, be calculated. These dimensions can be shown to give the maximum size of the average unit into which the D.N.A. is broken down by the D.N.A'ase. The cross-sectional area and volume, so calculated, are found to be 600A^2 and 2500A^3, and the molecular weight of the unit is therefore approximately 2400. This corresponds to the molecular weight of 7 or 8 nucleotides. It may be significant that Astbury has shown that there are x-ray reflections from D.N.A. corresponding to a repeat distance every 8 nucleotides.

* Supported by the U. S. Atomic Energy Commission.

X9. The Inactivation of Bovine Serum Albumin with Low Voltage Electrons. FRANKLIN HUTCHINSON AND BARBARA DOYLE, *Yale University.**—Monomolecular layers of bovine serum albumin (BSA) adsorbed on an evaporated chronium film were irradiated with electrons with energies ranging between 1 ev and several hundred ev. The biological activity of the BSA after irradiation was determined by measuring its ability to combine specifically with the homologous antibody. For one-volt electrons, no inactivation was observed with 10^{16} electrons/cm^2, but at 3 ev, inactivation was pronounced at about 10^{16} electrons/cm^2. Calculations indicate that the maximum temperature rise due to the electron bombardment was less than 1°C, so that the inactivation could not be thermal

but must be a breaking of some low energy bonds in the BSA molecule. As the incident electron energy was increased, the effectiveness for inactivation increased rapidly, and for 100 ev electrons only *ca* 10^{13} electrons/cm² produced inactivation. These measurements can be correlated with the events which cause inactivation of protein molecules and with the effects of secondary electrons released in biological material by the action of high energy ionizing radiation.

* Assisted by the U. S. Atomic Energy Commission.

X10. The Effect of Temperature and Ultraviolet Radiation on Dry Catalase.* RICHARD SETLOW AND BARBARA DOYLE, *Yale University.*—Dry crystalline and noncrystalline catalase, kept at temperatures from 90 to 363°K, have been inactivated by ultraviolet light of wavelength 2537A. At any one temperature the remaining catalytic activity depends exponentially on the number of incident quanta per cm², and hence an inactivation cross section may be found. The cross section for crystalline catalase is higher than for the noncrystalline variety. The cross section is not a constant but increases with temperature. At 90°K the cross section for noncrystalline catalase is 10^{-3}A²/quantum while at 363°K it is 12×10^{-3}A²/quantum. The low cross section at 90°K is a common property of all proteins. At this temperature a large amount of absorbed energy is trapped in metastable states and is not available for inactivation.[1] The trapping is negligible at room temperature. Above this temperature the chance of a broken bond recombining is small, and the inactivation cross section increases rapidly with temperature.

* Assisted in part by the U. S. Atomic Energy Commission.
[1] P. Debye and J. O. Edwards, Science **116**, 143 (1952).

X11. The Influence of the Host in Determining the Radiation Sensitivity of a Bacterial Virus.* MURRAY FRIEDMAN, *Yale University.*—Ionizing radiations have been utilized to investigate the infectious properties of a number of bacterial viruses. These studies have shown that in many cases the target volume and cross section for infectivity are smaller than the observed size of the virus. Some bacterial viruses have been characterized by the target sizes, using one host as a measure of infectivity, and it was considered of interest to determine whether the target volume and cross section would be altered if infectivity were measured as a function of three hosts. A bacterial virus, M-5, capable of attacking three strains of *Bacillus megaterium* (H1; H2; H3) was employed in this investigation. The hosts differed in many respects, i.e., generation time, spore formation, growth in synthetic medium, and plating efficiency of the virus. Two sources of ionizing radiation were used, 250 kv x-rays and 3.7 Mev deuterons. X-ray irradiations were performed wet and dry, and although the wet preparation was more sensitive, no difference could be observed in the respective inactivation doses of the virus when assayed against the three hosts. Also for deuterons the virus was found to have the same cross section (10^{-11} cm²) for all three hosts. These studies indicate that the target volume and cross-sectional area of the virus depend on the virus and are independent of the host.

* Assisted in part by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

X12. Radiation Sensitivity of Enzymes in Intact Cells.* W. F. POWELL AND ERNEST POLLARD, *Yale University.*—Studies of the effect of deuteron and electron bombardment on a number of enzyme molecules in semipurified form indicate that one primary ionization formed anywhere in the molecule will remove its biological action. To see whether this holds in intact cells the oxidative enzymes of *B-subtilis* were bombarded by deuterons both in a dried lysate and in intact cells. The subsequent loss of enzymatic function was the same in both cases, indicating that there is no change in radiation sensitivity. The manner of growth of the bacterium was found to exert an influence on both the lysate and the cellular enzyme. Grown on synthetic medium the enzymes were nearly twice as radiation sensitive. Taking the figures for complex medium growth the enzymes cytochrome oxidase and succinic dehydrogenase have molecular weights of 40 000 and 80 000, respectively.

* Assisted by the Atomic Energy Commission.

SATURDAY AFTERNOON AT 2:00

Shoreham, Terrace Room

(L. R. HAFSTAD presiding)

Apparatus of Nuclear Physics

XA1. A Double Crystal Neutron Spectrometer.* V. C. WILSON, B. W. ROBERTS, W. L. ROTH, J. S. KASPER, AND A. H. GEISLER, *General Electric Company Research Laboratory.*—A description will be given of a double-crystal neutron spectrometer that has been constructed for general use in structure studies. Several of the features are similar to features of the spectrometers of Wollan and Shull at Oak Ridge and Corliss and Hastings at Brookhaven. Some of the novel features include: a simplified mechanical system for orienting the Pb monochromator crystal; the use of the six-ton shield as a stable base for the entire spectrometer; a lever system for rotating the sample table at half the angular velocity of the detector arm; the use of a monitoring counter to stop the counting of the diffracted beam when a predetermined number of neutrons have impinged upon the sample; and a photographic system that records specific pertinent information. The photograph shows: the counts on three mechanical registers; a vernier reading that indicates the angular position of the diffraction counter; and auxiliary information, such as the temperature of a sample, or the current in an auxiliary magnet. A diffraction pattern obtained from a mixed ferrite will be shown. This pattern, which was obtained with one of the three collimators omitted, exhibits a resolution of about 30 minutes line width at half-maximum intensity.

* This instrument was built at Schenectady and is being used at the Brookhaven National Laboratory Pile.

XA2. Design of High Efficiency Low Background Fast Neutron Detector. S. D. BLOOM AND C. O. MUEHLHAUSE, *Brookhaven National Laboratory.**—A fast neutron liquid scintillation counter having a high efficiency for neutrons with energies between 0.25 Mev and 5.0 Mev is being constructed which has essentially no sensitivity to γ-rays and slow neutrons. The counter responds in a time $\sim5\times10^{-9}$ sec and can therefore be used in time-of-flight measurements. The body of the counter is 16 in. long and 16 in. in diameter. It is con-

structed of brass which is nickel-plated and aluminized on the inside. Twenty-five 5819 photomultiplier tubes view the scintillator through type 9-53 Corning glass filters. The scintillator consists of equal volumes of high purity toluene and methyl borate[1] into which is dissolved 200 g 2,5 diphenloxazole. This medium double pulses for fast neutrons as described previously,[2] except that the second pulse is primarily due to the 478-kev Li^{7*} γ-ray. Additional construction features will be discussed, as well as special experiments that can be performed with this type counter.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] C. O. Muehlhause and G. E. Thomas, Phys. Rev. **85**, 926 (1952).
[2] C. O. Muehlhause and G. E. Thomas, Nucleonics **11**, 44 (1953).

XA3. Observation of the Positive Ion Flux in a G-M Counter.* W. C. Porter and G. W. McClure, *Bartol Research Foundation*.—Measurements of the positive ion flux at the cathode as a function of time following the beginning of the discharge have been conducted. The flux measurements were accomplished by oscillograph presentation of the time variation of the ion current collected on a small plate spaced 2 mm outside of a gridded window in the cathode. The experimental results are in good qualitative agreement with a theoretical treatment of the positive ion motion given by Wilkinson.[1] The observed pulse of rate of arrival of ions at the cathode deviates somewhat from the theoretical pulse shape in virtue of the fact that diffusion effects were not considered in the mathematical analysis. Further confirmation of his theory was revealed when the arrival time of the ions was shown to be dependent upon the amount of charge present. This effect and a distribution of the times of origin of spurious counts will be presented by means of oscillograms. These studies were made with counter fillings of self-quenching mixtures of argon-alcohol, argon-butane, and argon-ether. A method for measuring the mobility of the positive ions by means of a more elaborate arrangement outside the gridded hole will also be presented.

* Assisted by the joint programs of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] D. H. Wilkinson, Rev. Sci. Instr. **23**, 463 (1952).

XA4. Corrections for Dead-Time of Counters in Coincidence Systems.* C. H. Westcott and J. S. Kirkaldy, *McGill University*.—An experimental investigation into counting loss corrections has now been completed, using methods already described.[1] With a nonextending dead-time τ_0 and a rate of occurrence of coincident events c and true singles rates $a+c$, $b+c$ in the two counters, respectively, the fraction of coincidences recorded is found to be $\gamma\rho_1\rho_2$, where $\rho_1=1/(1+\langle a+c\rangle_{Av}\tau_0)$, $\rho_2=1/(1+\langle b+c\rangle_{Av}\tau_0)$ and γ is a correlation correction factor given by $\gamma=1+c(1-e^{-\beta\tau_0})/\beta$, where $\beta=1.08(a^2+b^2+2abe\{[-a+b]/c\})^{\frac{1}{2}}$. Only if c/a, c/b are both small is $\gamma=1$. Random coincidences are additional, multiplying this counting rate by a factor $(1+(2ab+bc+ca)\tau_c/c)$, τ_c being the coincidence resolving time ($\tau_c<\frac{1}{2}\tau_0$); the usual expression $2N_1N_2\tau_c$ is incorrect. The corrections applicable if the particles arrive in "bunches," as from a pulsed accelerator, have also been studied and the results will be described. A full account of the investigation will be published shortly in the *Canadian Journal of Physics*.

* Supported by the National Research Council of Canada.
[1] C. H. Westcott and J. S. Greenberg, Phys. Rev. **83**, 242 (1951).

XA5. Gas Scintillation Counters. Carl O. Muehlhause, *Brookhaven National Laboratory*.*—The major types of radiation counters may be classified according to whether the medium employed is a gas, liquid, or solid and according to whether charge or light quanta is the fundamental energy form which is integrated into a pulse. Of these six combinations only the gaslight type has not been exploited. Aside from the possibility of fluorescent vapors or gases there exists the possibility of observing the light generated by ion recombination and excitation. Such a counter takes advantage of the effect (recombination) which limits the gas-charge type detector. An investigation of the light pulse generated by the passage of a Pu-α-particle in field free air, N_2, CO_2, H_2, BF_3, A, and He was made using a 5819 photomultiplier tube with and without phosphors of stilbene or NaI covering the light sensitive photosurface. Of the above mentioned gases only the noble ones yielded an observable effect. The number of cathode electrons liberated was $\lesssim 5$ per α-particle. Apparently only a few percent of the recombination or excitation events produce quanta suitable for detection by the 5819 photomultiplier tube. No pulse-height limitations were observed at 10 atmospheres pressure.

* Work carried out under contract with the U. S. Atomic Energy Commission.

XA6. Response of NaI(Tl) Scintillation Crystals as a Function of the Thallium Concentration.* F. S. Eby, W. K. Jentschke, and G. DePasquali, *University of Illinois*.—The dependence on thallium concentration of the fluorescent response of NaI(Tl) crystals to charged particles has been examined for crystals containing known amounts of Tl in the range from 0.01 to 1.0 percent by weight. The pulses from the scintillation detector were displayed on an oscilloscope and recorded photographically. The response for alpha-particles was studied at energies from 500 kev to 22 Mev. Pulse height *vs* energy plots show a region of nonlinearity which depends on the Tl concentration. Curves for crystals with low Tl concentration are nonlinear throughout the entire energy range investigated, whereas those for crystals rich in Tl show curvature for only the lower part of the energy range. At sufficiently high alpha-particle energies a linear relation is approached for all crystals. No deviations from linearity were observed in plots of pulse height *vs* energy for deuterons, protons, or electrons in crystals containing 0.17 percent Tl. The fluorescent efficiency reaches a maximum value for Tl concentrations of about 0.15 percent and decreases for higher concentrations, presumably because of a quenching effect. The decay time of the fluorescent radiation was found to be independent of the Tl concentration.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

XA7. Plastic Scintillators. R. K. Swank and W. L. Buck, *Argonne National Laboratory*.—Data on scintillation pulse size *vs* fluor concentration will be given for ten different polystyrene-fluor solid solutions and two polyvinyltoluene-fluor solid solutions. Further evidence has been found which supports the earlier proposition[1] that a nonradiative energy transfer occurs in these solid solutions. In addition, comparison of the pulse-height data with optical measurements gives strong support to the dipole-dipole interaction as a mechanism of energy transfer. These observations will be reported and discussed.

[1] W. L. Buck and R. K. Swank, Phys. Rev. **87**, 191 (1952).

XA8. The Stopping Power of Several Elements for Protons.* A. B. Chilton,† J. N. Cooper, and J. C. Harris, *Ohio State University*.—Experiments on stopping power have been carried out using the general technique of Madsen and Venkateswarlu.[1] Protons, accelerated by a Van de Graaff generator, were used in measuring stopping power for the gases nitrogen, neon, argon, krypton, and xenon and for the metals copper and nickel. Results were obtained for stopping of protons of energies between 440 and 1160 kev. Approximate values of the "straggling" in stopping power were also obtained for copper and nickel. For the sake of comparison with theory, data have been plotted as atomic stopping power divided by $Z^{\frac{1}{2}}$. On such a plot, the results are almost independent of Z for heavier elements and for energies higher than 700 kev. At

500 kev, however, preliminary results show that the metals are low as compared to the gases.

* Supported in part by the U. S. Atomic Energy Commission through a contract with the Ohio State University Research Foundation.
† Under sponsorship of the U. S. Office of Naval Research and the Naval Postgraduate School.
[1] C. B. Madsen and P. Venkateswarlu, Phys. Rev. **74**, 648 and 1782 (1948).

XA9. The Stopping Cross Section of Gases for Protons and Deuterons.* D. N. F. DUNBAR, H. K. REYNOLDS, W. A. WENZEL, AND W. WHALING, *California Institute of Technology.*—The stopping cross section of protons and deuterons in a number of gases has been measured for the equivalent proton energy range, 30–600 kev. A monoenergetic beam scattered at 90 degrees from a gold target surface passes through a 3-inch long chamber containing gas at 2–10 mm Hg between two $\frac{3}{32}$ inch diameter aluminum windows of about 10 kev total thickness. The stopping cross section ϵ is obtained from the measured pressure, the path length and the observed energy loss in the gas, with a probable error of 3 percent. Measurements on H_2, N_2, O_2, H_2O, NH_3, and N_2O indicate that Bragg's rule for the addition of stopping cross sections holds to within 2 percent for these compounds in the energy range 150–600 kev, while NO shows a deviation of about 4 percent. At lower energies deviations from the additive rule are large (~10 percent) in every case. The stopping cross section of carbon has been obtained from measured values for CH_4, C_2H_2, C_2H_4, C_4H_8, CO_2, O_2, and H_2 under the assumption that the additive rule is valid for these compounds. At energies above 100 kev, values for ϵ_{carbon} obtained from the different compounds are consistent to within about 5 percent. Below 100 kev deviations are large. Values obtained for ϵ_{air} give an integrated range in good agreement with previous measurements of the range in cloud chambers. Stopping cross sections obtained for the noble gases, He, Ne, A, Kr, and Xe will be presented.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission

XA10. Stopping Powers of Thin Compound Foils. JOHN PHELPS, W. F. HUEBNER, AND FRANKLIN HUTCHINSON, *Yale University.*—The stopping power for alpha-particles of several thin compound foils has been measured relative to aluminum. Alpha-particles from ThC′ deposited on a small metal button traversed the absorbing foil and entered a proportional counter through a thin window. Source and absorber were mounted inside a cylinder in which the air pressure could be varied. The distance from source to counter was approximately 10 cm. Curves of counting rate against pressure were plotted with various absorbers in the beam. Differences in stopping powers of the foils were determined from the displacements of the curves along the pressure axis. Stopping powers are expressed in mg per cm^2 equivalent to 1 mg per cm^2 of aluminum for alphas of about 6 Mev: mylar, 0.69; polyvinyl alcohol, 0.64; regenerated cellulose, 0.69; polythene, 0.59. Within the limits of experimental error these stopping powers agree with the values computed from the Bragg-Kleeman additive law.

XA11. Range-Energy Relation of Nitrogen Ions in Emulsion. H. L. REYNOLDS AND A. ZUCKER, *Oak Ridge National Laboratory.*—Range-energy relations of nitrogen ions in the energy region where the charge is a function of velocity have been investigated with the internal beam of the ORNL 63-inch cyclotron. Fifty-micron, Ilford C-2 emulsions were bombarded for short periods of time by a highly-attenuated nitrogen ion beam. After bombardment, the emulsions were surveyed for proton recoils resulting from elastic nitrogen-proton scattering. From conservation of energy and momentum considerations, the energy of the nitrogen ion directly after collision may be expressed in terms of the recoil proton energy and the angle between the scattered particles. The proton energy in turn may be determined from published proton range-energy data. To date, approximately one hundred events have been used to obtain a range-energy curve in emulsions for nitrogen ions between 3 and 20 Mev. A comparison of our results with the theory of Knipp and Teller[1] will be made.

[1] J. Knipp and E. Teller, Phys. Rev. **59**, 659 (1941)

XA12. Relativistic Rise in Ionization Loss in Nuclear Emulsions. BERTRAM STILLER AND MAURICE M. SHAPIRO, *Naval Research Laboratory.*—Further work has been done to delineate the shape of the ionization loss *vs* energy curve for relativistic charged particles traversing a nuclear emulsion. Multiple scattering measurements and "blob counts" were made on long tracks of electrons, mesons and protons with energies γ up to 3000 rest mass units. To avoid error arising from differences between plates, data were obtained from a single Ilford G-5 plate exposed at ~100 000 ft. Results are shown giving blob density G as a function of $\gamma-1$. The density G_{pl} at the Fermi plateau of ionization was found to be 1.14 ± 0.03 times G_{min}. This ratio is higher than Voyvodic's result; also, the rise from minimum to plateau is more gradual. The data are compared with Halpern-Hall theory for AgBr, using the ionization potentials of Bakker and Segré. Since only grains *along* the track were counted, the calculated energy loss is restricted to energy transfers less than an upper limit T. (Transfers $>T$ give rise to delta-rays, whose grains were not counted.) Calculations for two assumed values of T, 2 kev and 5 kev, fit the data equally well. They yield ratios G_{pl}/G_{min} of 1.15 and 1.14, respectively. Our results support the theoretical prediction that saturation of ionization loss sets in at $\gamma>100$.

XA13. Pellicle Stacks in Nuclear Research. FRANCIS W. O'DELL, MAURICE M. SHAPIRO, AND BERTRAM STILLER, *Naval Research Laboratory.*—Exposure of nuclear emulsions without glass support ("pellicles") in multilayered stacks for extending the continuously observable paths of charged particles was proposed by P. Demers. The lateral swelling (~25 percent) during processing, which discouraged the application of this technique, was overcome by the authors[1] in 1951. They evolved a successful method for mounting thick, stripped emulsions onto glass after exposure, but *prior to processing*, so that the pellicles can be developed as ordinary plates.[2] Since then, additional experience has been gained in the application of pellicle stacks to high energy physics. Our procedures lead to emulsions free from lateral swelling, free from blistering, and characterized by a level of distortion sufficiently low to permit multiple scattering measurements even on fairly "stiff" tracks. The advantages and limitations of this technique, its possible applications, details of the mounting procedure, and methods of following tracks from layer to layer are discussed.[3]

[1] Reported at the American Physical Society Meeting, Chicago, 1951. Phys. Rev. **85**, 712 (1952).
[2] We are indebted to Mr. C. Waller for advice.
[3] Methods of handling pellicles have also been developed by Professor C. F. Powell's group (private communication, D. H. Perkins).

XA14. A Possible "Bubble Chamber" for the Study of Ionizing Events. DONALD A. GLASER, *University of Michigan.*—It has been reported previously[1] that ionizing radiation can trigger violent eruptive boiling in a highly superheated pure liquid. Further work has shown that it is possible to photograph tracks of bubbles which mark the paths of ionizing particles passing through the liquid. It has also been possible to photograph counter-controlled eruptions initiated by minimum ionizing cosmic-ray particles. To date the liquid used has been diethyl ether at a temperature near 130°C and under a pre-expansion pressure of about 20 atmospheres. Under these conditions the bubbles grow to a size of about two millimeters in times of the order of 200 microseconds after the passage of the particle. The temperature range of sensitivity of the "bubble chambers" and "bubble counters" agrees roughly with calculated values.

[1] Donald A. Glaser, Phys. Rev. **87**, 665 (1952).

SATURDAY AFTERNOON AT 2:00

Wardman Park, Continental Room

(C. S. WU presiding)

Beta- and Gamma-Emitters, II

Y1. Decay and the β-spectrum of I^{129}.* E. DER MATEOSIAN AND C. S. WU, *Columbia University and Brookhaven National Laboratory.*—The β, γ, and x-radiations of I^{129} have been investigated with a magnetic spectrometer, proportional counter, and scintillation counter. I^{129} decays by β-emission to the excited state of Xe^{129m}. The excited state returns to the ground level by emitting a γ-radiation of 38 kev. The K conversion coefficient of this line is $\alpha_k = 18.5 \pm 3$, which classifies the radiation as M_1 type and is in good accord with the spin assignment. The β-spectrum was investigated in both solenoid spectrometer and NaI scintillation spectrometer. A NaI crystal was grown containing a small quantity ($<0.01\ \mu c$) of the radioactive I^{129}. The counting rate is practically zero below 38 kev, rises abruptly at 38 kev to almost its maximum value, then decreases gradually in the manner of a normal β-ray spectrum. The counting rate below 38 kev puts an upper limit on the ground to ground transition of less than 1 percent which is in good agreement with theoretical estimations of the branching ratio. The Kurie plot of the β-spectrum from the ground to the excited state transition ($\Delta I = 2$, no) shows a curvature concave upwards as in the case of Cs^{135} which is also a ($g_{7/2} \rightarrow d_{3/2}$) transition. Analysis of the spectrum and its comparison with other second forbidden transitions will be discussed.

* Supported by the U. S. Atomic Energy Commission.

Y2. The Radioactive Decay of Barium 131. J. M. CORK, J. M. LEBLANC, W. H. NESTER, AND M. K. BRICE, *University of Michigan.*—Spectrometric studies have been made of the radiations from sources of Ba 131, made by neutron capture in highly enriched Ba 130. In addition to photoelectrons from a lead radiator, about 35 conversion electron lines are observed photographically. The interpretation of these lines shows the existence of 13 gamma-rays, only six of which had been previously reported. Intensity ratios allow the multipolarities of six of the transitions to be rather uniquely established. A remarkably simple scheme of only seven levels can be proposed to satisfy completely the observed transitions. The energies of the levels are 0, 78.7, 133.6, 373, 497, 621, and 714 kev.

Y3. Gamma-Rays in the Decay of Ba^{131}. W. PAYNE AND M. GOODRICH, *Louisiana State University.*—The gamma-radiation from Ba^{131} have been investigated at this laboratory in a scintillation spectrometer. Gamma-rays at 122, 220, 370 and 500 kev are clearly resolved. Weaker gamma-rays are observed at 620 kev and approximately 100 kev. All of these except the 620-kev gamma-rays have been previously reported.[1,2] Coincidence measurements show the 120 kev and 500-kev gammas to be in coincidence. That the 620-kev peak is due to a crossover and not to sum pulses in the crystal is shown by measurements with sufficient lead absorber to eliminate the 122-kev peak. Two weak gamma-rays at 0.900 and 1.02 Mev of approximately the same half-life as Ba^{131} are observed but it is not yet possible to say whether they are due to an impurity. Measurements of relative intensity will be reported.

[1] Elliott, Cheng, Haskins, and Kurbatov, Phys. Rev. **88**, 263 (1952).
[2] R. Canada and A. C. G. Mitchell, Phys. Rev. **83**, 76 (1951).

Y4. Polarization Correlation of the Neodymium 144 Gamma-Cascade.* DONALD M. ROBERTS,† *Purdue University.*—The directional correlation of Nd^{144} as measured by Alburger and Kraushaar[1] can be interpreted as being due to a dipole-dipole or quadrupole-dipole transition between levels with spin 1–1–0 or a dipole-quadrupole transition between levels with spin 1–2–0. Because Nd^{144} is an even-even nucleus, the empirical Goldhaber-Sunyar rule favors the latter choice, and suggests that the ground and first excited states have the same parity. The polarization correlation of the Nd^{144} gamma-rays has been measured using apparatus similar to that described by Metzger and Deutsch.[2] The experimental data excludes an assignment of the same parities to all levels and seem to indicate a gamma-cascade in which the parity of the intermediate level is different from that of the other two levels. However, the 1-E1-2-E2-0 transition, required to satisfy the Goldhaber-Sunyar rule, cannot be excluded with certainty.

* Supported in aprt by the U. S. Atomic Energy Commission.
† Now at Canadian Westinghouse, Hamilton, Canada.
[1] D. E. Alburger and J. J. Kraushaar, Phys. Rev. **87**, 448 (1951).
[2] F. Metzger and M. Deutsch, Phys. Rev. **78**, 551 (1950).

Y5. Europium 147, 148, 149, and 150. REX C. MACK, J. J. NEUER, AND M. L. POOL, *Ohio State University.*—Bombardments of the enriched isotopes of samarium with 6.8-Mev protons produce the activities with half-lives of 13.7 hours, 24 days, 54 days, and 120 days. The activities are measurable in all the isotopes bombarded. On the basis of weighted initial saturation intensities and observed $p-n$, $p-\gamma$ cross sections, the 24-day activity is clearly assigned to Eu^{147} and the 120-day activity to Eu^{149}. The observations confirm the assignments of the 13.7-hour and 54-day activities to Eu^{150} and Eu^{148}, respectively. Examination of the 24-day activity in a scintillation spectrometer shows γ-rays of 0.120 Mev and 0.208 Mev. A magnetic spectrograph shows three groups of conversion electrons associated with these γ-rays. Absorption measurements show a 0.2-Mev particle and K and L x-rays. No positrons were observed. A decay scheme is suggested. Associated with the 120-day activity, absorption measurements show a 0.2-Mev particle, a γ-ray of approximately 0.25 Mev, and K and L x-rays. No γ-rays are associated with the 13.7-hour activity. This lack of γ-rays and the log ft value of 6.4 indicate a forbidden transition. The energy of the beta-particle is 1.1 Mev. The 54-day activity shows a 0.58-Mev γ-ray, associated conversion electrons, and K and L x-rays.

Y6. A Decay Scheme for $_{66}Dy^{165m}$ (1.25 min) and $_{66}Dy^{165}$ (2.3 hr). W. C. JORDAN, J. M. CORK, AND S. B. BURSON, *Argonne National Laboratory and University of Michigan.*—The activities induced by neutron capture in $_{66}Dy^{164}$ have been studied with 180° photographic internal conversion electron spectrometers and with the Argonne Laboratory scintillation coincidence spectrometer. $_{66}Dy^{165m}$ (1.25 min): The metastable transition energy was found to be 108 ± 0.2 kev. Internal conversion lines from the K, L_2, L_3, M_2 and/or M_3, and N_4 and/or N_5 shells were observed. The K/L ratio is 0.15 ± 0.05. $_{66}Dy^{165}$ (2.3 hr): Beta-decay of $_{66}Dy^{165}$ leads to excited states of $_{67}Ho^{165}$ from which gamma-rays of 94.4 ± 0.2, 279.4 ± 0.8, 361.2 ± 1.0, 634 ± 3, 710 ± 20, and 1020 ± 30 kev were observed. Weak internal conversion of the latter two permitted their observation only with the scintillation spectrometer. The K/L ratio of the 94-kev transition is 7.7 ± 2.0. K/L ratios of the 279- and 364-kev transitions are also large (>5). Gamma-gamma coincidences were observed between members of the pairs (279) (710) and (361) (634). No other gamma-gamma

coincidences were detected. The results of beta-gamma coincidence experiments indicate that the 94-kev gamma-ray is coincident with a beta-transition of about 1.3 Mev, while the 279-, 361-, 634-, and 710-kev gamma-rays are coincident with a softer beta-component (~0.3 Mev). A decay scheme will be presented.

Y7. The Argonne Laboratory Scintillation Coincidence Spectrometer. S. B. BURSON AND W. C. JORDAN, *Argonne National Laboratory.*—To facilitate correct assignment of the radiations of radioactive isotopes into consistent decay schemes, an instrument for analyzing the gamma-ray spectra and for determining the coincidences between various radiations has been constructed. We are indebted to Mr. Thomas Brill, Head of the Argonne Electronics Section, and to Mr. James McMahon for their cooperation in designing and constructing this instrument in accordance with our specifications. A ten-channel differential pulse-height analyzer and a single-channel analyzer are incorporated into a coincidence circuit. Type 5819 photomultipliers are used in conjunction with either NaI(Tl) or anthracene crystals. With the coincidence circuit off, the ten-channel analyzer may be used to investigate the normal spectrum of gamma-rays. The single channel may then be set to accept any selected region, and an analysis of the coincidence spectrum obtained. Application of the instrument will be demonstrated by showing how the 634- and 710-kev gamma-rays following beta-decay of $_{66}Dy^{165}$ have been resolved and matched to the 361- and 279-kev components. Utilizing the beta-ray counter, coincidences between all four gamma-rays and a beta-ray of about 300 kev are observed, providing evidence that the two cascade pairs (279) (710) and (361) (634) are in parallel.

Y8. Branching Ratio in Re^{186}.* J. E. ROBINSON, C. E. WHITTLE, AND P. S. JASTRAM, *Washington University.*—The decay of Re^{186} includes a low intensity 0.3-Mev beta-ray followed by a gamma-ray, either to the first excited state (0.625 Mev) or to the ground state (0.764 Mev). The relative abundance of this branch has been determined by an absorption experiment[1] to be about 0.4 percent of the negatron decays. During a study of the Re^{186} decay, we have determined the relative abundance of this branch by three different methods, with the following results: (a) Beta-ray intensities, magnetic spectrometer:[2] 2.0 percent; (b) scintillation counter, comparison of gamma-rays with those in other branches: 0.12 percent; (c) substitution method involving comparison of beta- and gamma-radiations with those from an activity of known decay: 0.08 percent. It is evident that the results obtained by the latter two methods agree fairly well with each other, but do not agree at all with the value found from the beta-spectrum. It is possible that the two extrapolations and subtractions required, as well as the probability of scattering, conspired to give too high a value for the intensity of the low energy group. It appears likely that the absorption measurement may be less accurate than (b) or (c).

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] F. R. Metzger and R. D. Hill, Phys. Rev. **82**, 646 (1951).
[2] F. T. Porter (private communication).

Y9. Beta-Gamma Correlations in the Decay of Re^{186}.* C. E. WHITTLE, J. P. HURLEY, AND P. S. JASTRAM, *Washington University.*—Recent work[1] on the beta-spectrum of Re^{186} points toward a ground-state spin, for this nuclide, of 0 rather than the previously reported value[2] 1. The beta-gamma angular correlations in the decay to the 137-kev first excited state of Os^{186} holds promise of deciding between the two possible spins. The assignment 2-even for the 137-kev state appears to be on very safe ground. If the ground-state spin of Re^{186} is 0, the expected beta-gamma correlation is large and is unaffected by nuclear charge; if it is 1, the correlation is likely to be less pronounced and is subject to being washed out by the Coulomb field of the nucleus. Beta-gamma angular correlations have been determined for two different source conditions: A concentrated solution held in a thin-walled capillary tube, and a fairly thin deposit of rhenium nitrate on a quarter-mil aluminum foil. Some of these experimental details and the results will be described.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] F. T. Porter (private communication).
[2] F. R. Metzger and R. D. Hill, Phys. Rev. **82**, 646 (1951).

Y10. The Disintegration of W^{185}.* N. LAZAR, R. J. D. MOFFAT, AND L. M. LANGER, *Indiana University.*—Recent review articles[1] on nuclear energy level schemes have assigned a gamma-ray of 0.134 Mev to follow the 0.43-Mev beta-transition from the 73-day level in W^{185}. The basis for this assignment appears to depend mainly on a brief report by Cork *et al.*[2] A careful search for such a gamma-ray was made with a NaI scintillation spectrometer, and for possible internal conversion electrons with a magnetic spectrometer employing a thin window counter. The existence of Ta *X*-radiation and weak gamma-radiation probably associated with the electron capture of some W^{181} impurity was observed from a source obtained from Oak Ridge. However, no evidence was found for any 0.134-Mev gamma-radiation of the intensity suggested by the proposed decay scheme. Since the 0.435 Mev beta-spectrum of W^{185} does not exhibit a unique forbidden shape and since the *ft* value is appropriate for a once forbidden transition, it is suggested that the beta-transition is from a $p_{3/2}$ ground level of W^{185} directly to the $d_{5/2}$ ground state of Re^{185}.

* This work was assisted by a grant from the Fredrick Gardner Cottrell Fund of the Research Corporation and by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952); R. W. King (to be published); and Hollander, Perlman, and Seaborg (to be published).
[2] Cork, Keller, and Stoddard, Phys. Rev. **76**, 575 (1949).

Y11. Neutron Deficient Isotopes of Hg.* J. W. MIHELICH, *Brookhaven National Laboratory*, AND L. P. GILLON,† K. G. KRISHNAN, AND A. DE-SHALIT, *Princeton University.*—Gold was irradiated with protons of various energies in steps of 10 Mev up to 105 Mev in the Harvard cyclotron. The products of the Au(*p*, *xn*)Hg reaction were distilled onto thin foils and some 230 conversion electron lines (~8 kev to 320 kev), were photographed on 175 spectrograms in permanent magnet spectrographs. The lines were classified as to energy, intensity, decay rate, threshold for production, and excitation function and decay schemes were then proposed. Hg^{193m} (10 hr) decays to levels analogous to those in Hg^{195m} and Hg^{197m}.[1] The 136 kev *M*4 in Pt^{193m} is fed by Au^{193}. Hg^{192} (6 hr) decays to Au^{192} in which several γ-rays are observed, the most prominent of which are 31.4 and 157 kev. Hg^{191} has a *K*-capture lifetime of ~1 hr. Au^{191} has transitions of 13.9 and 252 kev, analogous to those in the other Au^{odd} nuclei. No prominent Hg transitions are seen. 30 minute Hg^{189} is observed via a 28.6-kev transition in gold. It is noted that the $d_{5/2}-d_{3/2}$ separation for Au^{odd} is remarkably uniform, varying smoothly from 252 kev (Au^{191}) to 279 kev (Au^{197}). Apparently the $p_{3/2}$ level has crossed the $p_{1/2}$ level in $Hg^{195,193}$.

* Work supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† On leave from Nuclear Physics Center, Louvain University, Belgium.
[1] O. Huber *et al.*, private communication; Mihelich and de Shalit, Phys. Rev. (to be published).

Y12. Genetic Relationships of the 0.8-Second Pb^{207m} Isomer.* G. FRIEDLANDER AND ELIZABETH WILSON, *Brookhaven National Laboratory*, AND A. GHIORSO AND I. PERLMAN, *University of California.*—The assignment of the 0.8-second lead isomer to mass 207 has been confirmed by its chemical separation from long-lived Bi^{207}. The Bi^{207} was adsorbed on nickel

powder placed on a sintered glass funnel, and the lead activity was separated with good efficiency in about one second by pulling hot 0.5 N HCl through the deposit into a flask placed on a scintillation counter. The measured half-life was 0.88 ±0.10 second. Pulse-height analysis showed that both the 0.55 and 1.05-Mev gamma-rays associated with Bi^{207} appear in Pb^{207m}, in about the same intensity ratio as in the equilibrium mixture. No other gamma-energies were found in Pb^{207m}. Pb^{207m} was also searched for as a product of Po^{211} decay. Recoil atoms from Po^{211} (in equilibrium with At^{211}) were collected on a charged foil under a scintillation crystal; after each collection the At^{211} was removed and counts were taken for 3 seconds. No short-lived activity was found. This result, together with separately measured counting and recoil efficiencies, leads to an upper limit of 5×10^{-6} for the fraction of Po^{211} decays going to Pb^{207m}.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.

Y13. Chemical Separation of 0.82-sec Pb^{207m} from Bi^{207}. E. C. CAMPBELL AND F. NELSON, *Oak Ridge National Laboratory*.—To show that the 0.82-sec isomer, Pb^{207m} previously reported,[1] is also produced through the decay of the 50 year Bi^{207}, a rapid chemical separation has been made. It is based on the discovery[2] that in chloride solutions (Bi^{III}) is considerably more strongly adsorbed than is Pb^{II} on certain anion exchange resins (e.g., Dowex 1). The Bi^{207} activity could be fixed on about 1 cm^3 of the resin in 0.5 N HCl. The Pb^{207m} daughter produced by the Bi^{207} decay diffuses to some extent out of the small resin spheres into the interstitial solution. When a few drops of this solution are transferred rapidly to a counter, the short period is immediately evident from the rapid decrease in the observed counting rate. This result definitely establishes the genetic relationship. Further studies of the Pb^{207m} are being made in a continuous flow arrangement.

[1] E. C. Campbell and M. Goodrich, Phys. Rev. **78**, 650 (1950).
[2] K. Kraus and F. Nelson, private communication.

SATURDAY AFTERNOON AT 2:00

Shoreham, West Ballroom

(R. R. WILSON presiding)

Invited Papers on Mesons

Z1. The Pi-Mesic Atom. J. B. PLATT, *University of Rochester*. (30 min.)
Z2. Mesons and Fission. EMILIO SEGRÉ, *University of California, Berkeley*. (30 min.)
Z3. Photoproduction of Neutral Mesons in Hydrogen and Deuterium. ALBERT SILVERMAN, *Cornell University*. (30 min.)
Z4. Scattering of Mesons by Protons. F. J. DYSON, *Cornell University*. (30 min.)

SUPPLEMENTARY PROGRAMME

SP1. The Structure and Aging of Thin Metal Films III.*† RICHARD B. BELSER AND ROBERT J. RAUDEBAUGH, *Georgia Institute of Technology*.—It has been shown that thin metal films undergo changes in structure and resistivity with time and heating. These changes appear to be caused by the action of thermodynamic and surface forces and by the effects of contamination and corrosion. Use of the evaporation technique and a proper selection of the noble metals permits the minimization of the latter considerations. Films of gold deposited in a vacuum of 10^{-5} mm of Hg and aged by heating therein have shown reduction in resistance from approximately 2 ρ_b to 1.3 ρ_b. Comparable results for silver, copper, and aluminum have been obtained by using suitable procedures. Resistance *versus* thickness curves for each metal before and after aging have been plotted over the range 250–1500 angstroms. Sputtered films of silver, gold, and platinum showed initial resistivities of 2.5–5 ρ_b dependent on the rate of deposition and the heating caused thereby. The resistivities of these films drop to 1.5–2 ρ_b upon proper heat treatment. The somewhat higher final resistivity for sputtered films is ascribed to lattice defects caused by inclusions and ionic bombardment during deposition. The effects of recrystallization, aggregation, and corrosion on measured values of resistivities are emphasized.

* To be given at the end of Session FA if the Chairman rules that time permits.
† Supported by U. S. Army Signal Corps.

SP2. Relativistic Particle Cyclotron with Electrostatic Focusing.* H. F. KAISER, *Naval Research Laboratory*.—In order that all circular orbits in a cyclotron have the same rotational periods, it is necessary that the magnetic field increase in a definite way with radius. Such a field is a defocusing field. It is proposed to utilize such a magnetic field and devise electrostatic means to correct for the defocusing action. The possibilities and limitations of some possible electrode configurations and the effects of radial electric field components on the particle motion will be discussed.

* To be given at the end of Session J if the Chairman rules that time permits.

SP3. The Deuteron-Proton Magnetic Moment Ratio.*† T. F. WIMETT,‡ *M.I.T.*—The nuclear magnetic resonance absorption method has been applied to a high precision determination of the ratio of the deuteron magnetic moment to that of the proton, with the following result, as measured in hydrogen deuteride gas for which no molecular shielding corrections are needed:[1]

$$\mu d/\mu p = 0.307012192 \pm 0.000000015.$$

The given error is five times the standard deviation of results obtained in four independent measurements. A magnetic field inhomogeneity of only 3 parts in 10^7 was achieved over the volume of the sample by means of empirically shaped concave

pole faces and an array of current coils mounted on the pole faces for final field smoothing. A new method was developed for the frequency ratio measurement in which the two frequencies were generated from combinations of harmonics and subharmonics of a single low frequency master oscillator. The inherent uncertainty of this method was less than 1 part in 10^9 and contributed a negligible part of the error quoted above.

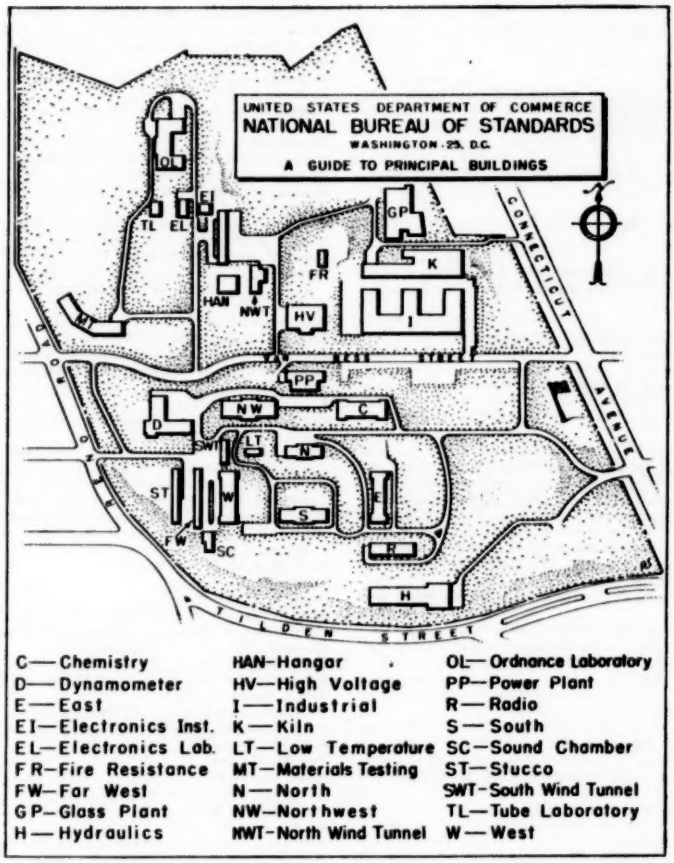
* To be given at the end of Session Q if the Chairman rules that time permits.
† This work has been supported in part by the Signal Corps, Air Materiel Command, and the U. S. Office of Naval Research.
‡ Now at the Los Alamos Scientific Laboratory.
[1] N. F. Ramsey, Phys. Rev. **85**, 688 (1952).

SP4. The Excitation Energies of Nuclei as Rational Multiples of the Electron Mass.* ENOS E. WITMER, *University of Pennsylvania.*—The writer has pointed out before[1] that the excitation energies of nuclei should be rational multiples M of the rest mass of the electron m according to his ideas. Thus every excitation energy can be written as Mm with M rational. Using only the most accurately measured values, the writer has made a list of 236 such excitation energies. In this list there are 22 for which M is an integer to within ± 0.02. The probability of this happening by chance is only 15×10^{-6}. If only the fractional parts of these M numbers are plotted on a straight line between zero and one, it is found that there are other concentration points besides zero and one. This is emphasized by the fact that there are 82 M values which can be identified as lying within ± 0.02 of the rational numbers p/q with $q=1, 2, 3,$ or 4 and p integral. The probability of this happening by chance is only 5.7×10^{-5}. We think this is strong support for our idea that the masses of nuclei in any state are Mm with M a rational number.

* To be given at the end of Session T if the Chairman rules that time permits.
[1] E. E. Witmer, Phys. Rev. **89**, 905 (1953).

SP5. Special-Relativistic Linear Theory of Gravitation.* J. C. SWIHART AND F. J. BELINFANTE, *Purdue University.*—To avoid divisions by zero, the special case $b=q=0$ of the gravitation theory reported earlier[1] is treated separately. In this case, there is always a static spherically symmetric solution around a point particle at rest. The field is now approximately Newtonian if $2(a+4f)=C^2-4KC+16K^2+3C^2f/a$. The advance of the perihelion of mercury is then $(7N)''$/century, where $N=(C^2+8KC-16K^2+7C^2f/a)/2(a+4f)$. As only the ratios a/C^2, f/C^2, K/C have a physical meaning, and $C\neq0$ for agreement with experiments, we normalize by $C=1$. We put $f=-\xi a$. The planetary problem can be solved with also $K=0$ (interaction of gravitational field with energy tensor only). This requires $2a=(3\xi-1)/(4\xi-1)$ and yields $N=(7\xi-1)/(3\xi-1)$, so that Einstein's perihelion precession ($N=6$) then is found for $\xi=5/11$, $a=2/9$. This gives 1.97″ for the light deflection near the sun. Einstein's result 1.75″ can for $N=6$ be obtained only by including the interaction with the rest mass density ($K\neq0$), e.g., choosing $C=1$, $K=1/16$, $a=1/4$, $f=-5/64$, $b=q=0$. For the red shift one always finds Einstein's value whenever the conditions for approximately Newtonian gravitation are fulfilled.

* To be given at the end of Session RA if the Chairman rules that time permits.
[1] F. J. Belinfante and J. C. Swihart, Bull Am. Phys. Soc. **28**, No. 1, 28 (1952).


UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON 25, D.C.
A GUIDE TO PRINCIPAL BUILDINGS
OL
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CONNECTICUT
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PP
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TILDEN STREET
C—Chemistry
D—Dynamometer
E—East
EI—Electronics Inst.
EL—Electronics Lab.
FR—Fire Resistance
FW—Far West
GP—Glass Plant
H—Hydraulics
HAN—Hangar
HV—High Voltage
I—Industrial
K—Kiln
LT—Low Temperature
MT—Materials Testing
N—North
NW—Northwest
NWT—North Wind Tunnel
OL—Ordnance Laboratory
PP—Power Plant
R—Radio
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SC—Sound Chamber
ST—Stucco
SWT—South Wind Tunnel
TL—Tube Laboratory
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Tiniot, J. H.—M4
Tittman, J. and F. F. Johnson—G15
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Toppel, B. J. and S. D. Bloom—PA8
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